Water Power

INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER

PRICE 2/6 FEBRUARY 1957

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ENGINEERING

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1951 FASNAKYLE
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1955 CLACHAN
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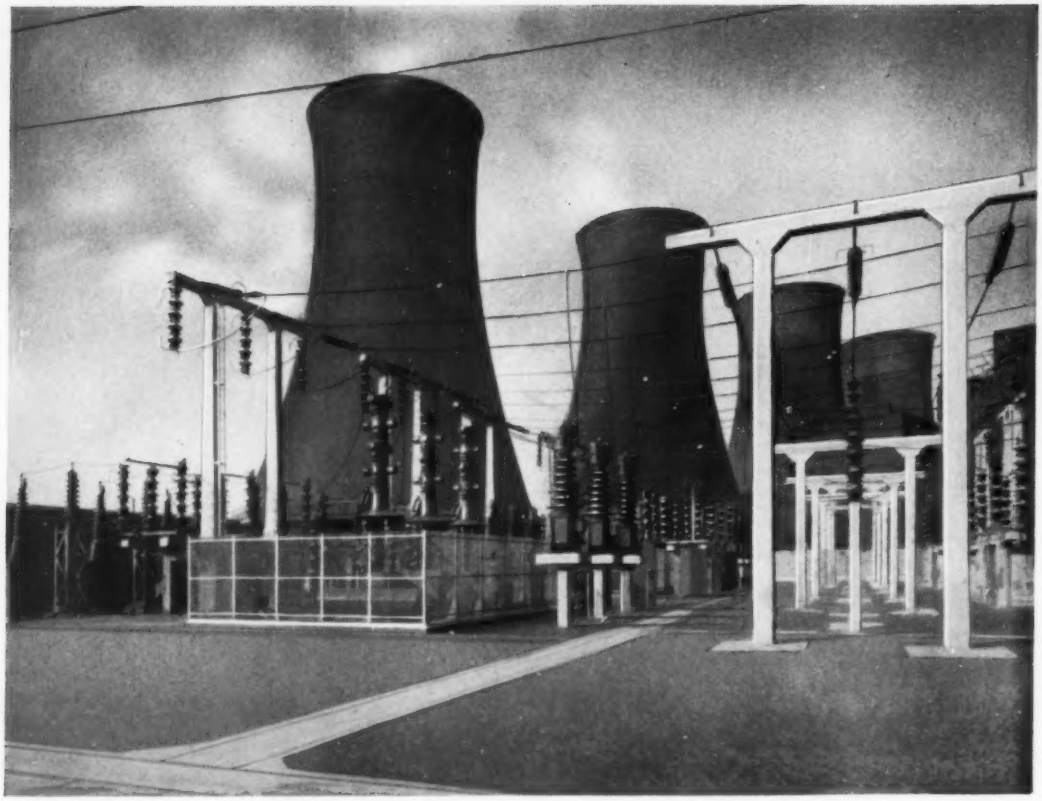

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-electric developments

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Volume 9 Number 2

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Europe's Energy Gap

ACCORDING to a report issued by the Economic Commission for Europe the electric power consumption for the whole of Europe, that is, including the U.S.S.R., reached a total of 625,000 million kWh in 1955. This represents an increase of 10·6% compared with 1954, a figure which cannot be regarded as being at all satisfactory. In the same year the United States increased their power supplies by 15%, in spite of the very much higher consumption *per capita* in that country. Another alarming feature of the power situation in Europe is the increasing extent to which it is becoming dependent on imported sources of energy, especially in the matter of American coal which has to be paid for in precious dollars. In an attempt to overcome this dangerous deficit, the Economic Council has set up an Energy Advisory Commission, composed of five independent experts, charged with the duty of finding a solution to this problem.

Although power-transmission networks continue to extend, the report goes on to say, there are as yet few new lines across frontiers. This is a matter which should receive urgent attention as there are still areas in Europe with sufficient indigenous sources of power, chiefly hydraulic, capable of providing guaranteed supplies on long-term contracts which would seem to call for intensive development. Some of these sources, of course, are already being studied, such as the "Interalpen" scheme for Austria and the "Yougelexport" for Yugoslavia, but the rate of progress seems to be lamentably slow and altogether incommensurate with the urgent need for additional energy.

Other important potentialities lie in the exploitation of the Danube and certain rivers in northern Greece, notably the Aliakon and the Nestos, and it is understood that investigations are now being undertaken.

One of the items on the agenda was the discussion of a report by the Group of Experts on the study of hydro-electric resources of Europe, but apart from confirming that the assessment of the gross mean annual run-off potential should form the foundation of the Group's work on the determination of hydro-electric resources as a whole, and adopting a formula which would allow maps of gross annual hydro-electric potential to be completed on a common basis in different countries, nothing of much immediate practical value seems to have been achieved. It might be added that the Group's experts have considered various possible methods of defining net hydro-electric resources and of comparing gross and net possibilities, and made "a draft recommendation pointing out the effect of changes in water temperature in rivers of common interest." This last investigation will no doubt lead to information of enticing interest but it does not seem to us to represent a notable step forward in meeting an urgent need for power.

Other questions coming up for consideration concern:—

The development of international transport systems for energy exchanges and the elimination of obstacles to such exchanges;

Projects of general interest for the supply of energy to Western Europe, for which it has not proved possible to raise the necessary capital;

The scope for increasing production, or the capacity for production, by freeing the international movement of manpower;

What new steps, if any, can be taken to exchange technical information and what scope is offered for joint programmes of applied research on the production and efficient utilisation of energy.

Also included in the programme are three proposals presented, respectively, by Czechoslovakia, Romania and the U.S.S.R. The first proposal is that information should be exchanged on the operation of large interconnected networks, and the second that an expert study should be made of the technical and economic aspects of automatic and remote control of power systems. The U.S.S.R. proposal concerns two studies; one with a view to promoting the development of high-voltage transmission lines, both for alternating and for direct current, and the other to establish data

on the operation of large-capacity generators, transformers and high-voltage cables.

All these studies and investigations are necessarily concerned with long-term results and do not appear to us to harmonise very well with the need which the Commission recognises to make up "an energy deficit which is likely to grow" and we should have thought that something more immediate and drastic would have been desirable.

I.A.H.R. Lisbon Congress

THE International Association for Hydraulic Research is to hold its Seventh Congress from July 25 to 31 at Lisbon. Papers are being requested under four headings: (1) Scale effect; (2) Cavitation; (3) Hydraulics of water-intake works, tunnels and entrance channels and diversion tunnels; and (4) Free subjects. It is expected that visits will also be arranged to Lisbon harbour and to the National Civil-Engineering Laboratory, as well as to hydro-electric and irrigation schemes. The Congress is open to non-members, and fuller details are available from Laboratorio Nacional de Engenharia Civil, Avenida do Brasil, Lisbon, Portugal.

Hydro Power for International Nickel Company

PLANS are in hand for exploiting a large reserve of nickel ore by The International Nickel Company of Canada Limited, who are to open up two new mines in Northern Manitoba, a development which will increase the company's nickel production by 50%. Power is to be provided by the Manitoba Hydro-Electric Board who have agreed to undertake the construction, at an estimated cost of $32-38 million, of a large hydro-electric generating station at Grand Rapid on the Nelson River. The power potential has not yet been fully investigated but it is expected to be sufficient not only for the new mines when operating at their ultimate output, but also to meet the needs of new industries which it is hoped to create in Northern Manitoba.

The new project will be situated about 400 miles north of Winnipeg and International Nickel is to assist the Province during the construction period by a four-year $20 million loan, which will ultimately be converted into debentures repayable in instalments over a period of 20 years.

Metal Corrosion and Conservation

AT a recent meeting of the Institution of Civil Engineers, Dr. W. H. J. Vernon stated that metallic corrosion was costing the United Kingdom about £600 million annually, and that without prejudice to existing research centres a corrosion research station on a truly national basis should be established. He pointed out that the vast sum mentioned only included the probable cost of maintenance plus the cost of the equipment which corrosion makes unserviceable every year, and not the indirect costs of breakdowns from such items as, say, a perforated tube in a power-station condenser, which were quite incalculable.

He suggested that the corrosion specialist should become a normal part of the industrial establishment. Amongst all the errors of design, he added, the most common was still that of coupling together dissimilar metals or alloys without regard to their nature or to the consequences that may follow when the assembly goes into service, as the juxtaposition of certain metals would frequently accelerate the corrosion of one of them. In certain situations he considered cathodic protection to be one of the most promising fields for development. Not only could it prevent corrosion when installed in the first instance, but in one case at least it had successfully inhibited leaks which had developed in bitumen-coated steel water mains. In the seven previous years there had been 25 leaks, each of which had cost about £500 to repair, including the cost of interrupting operations; it would have cost between £60,000 and £70,000 to replace the pipes. Cathodic protection was installed at a cost of £2,800 and protection was assured for a running cost of £60 per annum.

Mayurakstra Station in Commission

WEST Bengal's first major hydro-electric generating station went into action on December 16, 1956. The station is 170 miles from Calcutta, at the Canada dam site of the Mayurakshi reservoir project at Messagjore. It has been equipped by the Canadian Government under the Technical Assistance scheme of the Colombo Plan. Sir Dhiren Mitra, Chairman of West Bengal's Electricity Board, switched on the supply which flowed through 75 miles of transmission lines. Although irrigation and flood control are the first objects of this project, it is also expected to provide power supply for the rapid development of the cottage and other small-scale industries in the area.

Rio Grande Project

ACCORDING to Mexican information, Brazil is planning a U.S. $300 million hydro-electric installation at Furnes on the Rio Grande River. The plant would have a capacity of 1,200 MW. Project planning has been done by large Canadian and American companies and Brazilian Federal State Government. Power from the plant would go to serving growing industry in that region. Existing installations in the area also are being expanded.

Scottish Developments

THE North of Scotland Hydro-Electric Board have brought into operation recently a further 9,200 kW of generating plant at a number of widely separated places ranging from Allt-na-Lairige in Argyll, Achanalt in Ross-shire and Storr Lochs on the Island of Skye.

At the mouth of the Allt-na-Lairige which is a high-level stream with a steep fall flowing into the River Fyne, a new power station of 6,000 kW has just been finished. The associated dam, 73 ft. in height and 1,375 ft. in length, is of special interest as it is one of the first, if not the first, prestressed concrete dam ever to be designed as such. It is anchored to its rock foundations by groups of steel rods and by adopting this form of construction there has been a saving of about 40 per cent. in concrete.

The generating plant is a twin runner horizontal Pelton machine, the alternator being situated between two Pelton wheels operating under a gross head of

817 ft. It is remotely controlled from the control room of the Shira scheme.

The new power station at Achanalt is on the River Bran which is a tributary of the River Conon. The works consist of a barrage across the outlet of Loch a'Chuilinn, a tunnel, and a power station situated in a rocky gorge on the River Bran almost within sight of the Grudie Bridge station. The barrage regulates the flow of water to the turbine which drives the 2,400 kW generator in a stone-built power station built unobtrusively into the rock of the gorge. The generator is of the induction type and is one of the largest of this type so far used anywhere. The output of the station is controlled automatically by the level of the water in the headpond which serves the station, or manually from Grudie Bridge, so that normally it will be unattended.

At Storr Lochs in the north of Skye, a second pipeline has been constructed down the cliff face to the power station on the sea shore and a third 800 kW generator has been installed.

Large Swedish Turbine Order

THE Swedish State Power Board has placed an order for two turbines with Nydqvist & Holm, Trollhättan, to be installed in the Porsi power station on the Lule river in northern Sweden. These turbines will be the most powerful of their kind in Sweden. The power station is intended for three units but only two will be installed in the first instance. The turbines are of the Kaplan type. The net head will vary between 33 and 36 m. At 36 m. the maximum output of each turbine will be 131,000 h.p. at 115 r.p.m. and the discharge rate of water per unit 300 cu. m. per sec. The combined capacity of the two units will be 160,000 kW and the annual production will amount to 960 million kWh. The power station will be ready for service in 1960-61, and the cost has been estimated at 122 million Swedish crowns.

New Hydro-electric Projects for West Bengal

THREE projects, the Jaldhaka, the Balasun and the Teesta, have been in cold storage for the past 25 years. It is understood that the first two will be taken in hand during the current Second Five Year Plan. The funds so far provided for them, however, are hardly sufficient. It is generally believed that the Third Plan will give the first priority to power and it is not expected that West Bengal will be effectively on the hydro-electric map of India until then.

Hydro-Electric Dam Construction Data

DETAILS of a broad range of cost-saving devices and new methods in the construction of hydro-electric installations will be made available to interested experts as a result of a meeting of specialists held recently in Geneva. The meeting, sponsored by the United Nations Economic Commission for Europe's Electric Power Committee, examined forty-three reports prepared by experts from Spain, Finland, Greece, Italy, Portugal, Federal Republic of Germany, Sweden, Turkey, U.S.S.R., Austria, Romania, Czechoslovakia and the United States. Many of the papers were illustrated with slides, charts, diagrams and photos. They dealt with the characteristics of hydro-power stations constructed in various countries since World War II, on advances and future prospects in the construction of hydro-power stations through better organisation and mechanisation, and on construction methods saving cement, metal consumption and manpower. A number of films on various phases of dam construction were shown during the meeting.

General rapporteurs were appointed to prepare statements covering the reports submitted for each section as well as the discussion which followed. A volume containing the statements, and summaries in the three working languages of the ECE—English, French and Russian—of all the reports which were presented, will be issued shortly.

The meeting of specialists proposed that the Secretariat draw up a bibliographical index of works published in the field of hydro-electric construction and installations with a brief abstract accompanying each title.

Ceannacroc Generating Set

A 16,000 kW water-turbine generating set was recently put into commission by the North of Scotland Hydro-Electric Board at their underground power station at Ceannacroc, the commissioning of which we announced last month. The 22,300 h.p. turbine is of the vertical reaction type and operates at 375 r.p.m., under a net head of 250 ft. Water enters the turbine through a 6 ft. 4 in. diameter "Straightflow" valve with an automatic by-pass valve for filling the spiral casing. This casing, of welded steel plate, was transported to site in one piece. The runner is of fabricated construction and the thrust is taken by a combined thrust and guide bearing above the alternator rotor hub.

An 11 kV, 3 phase, 50 cycle alternator is provided and can operate as a synchronous condenser if required. It is a two-bracket machine, a guide bearing being provided below the alternator rotor hub in addition to the combined thrust-and-guide bearing which takes the weight of the alternator rotor, turbine rotor and hydraulic thrust. This equipment was supplied by the English Electric Co. Ltd. who also supplied the automatic voltage regulator, which incorporates magnetic amplifiers. Two similar generating sets are being supplied to the Board's power station at Glenmoriston.

Mexican Developments

CONSTRUCTION will start on a regulating dam on the Lerma River in the State of Michoacán which will incorporate a 250 MW electric power station thus solving completely the electricity problem in the centre of the Republic. It would also be possible to irrigate 25 thousand hectares in the states of Michoacán and Guanajuato.

The Director of the Mexican Federal Electricity Commission recently stated that the generating plant at Tingambato with a capacity of 150 MW would be inaugurated in March 1957, and that the transmission line was well on its way, its towers having already reached the Federal District. The power generated by this plant would be connected to the network of the Cia. de Luz y Fuerza. With respect to the plant at Temazcal, in the Papaloapan basin, the Director of the F.E.C. stated that it would have four units of 37 MW capacity each. The first unit would supply the power for the Benito Juárez paper factory.

Fig. 1. View from upstream during filling of reservoir

Roxburgh

The Roxburgh Hydro-electric Project, South Island, New Zealand, is now in operation

NEW Zealand's £30 million Roxburgh hydro-electric scheme, which began production of power on two of its eight generators on July 26, 1956, is the first water-power project to be built on the Clutha, which has the largest flow of any river in New Zealand. This river has an ultimate hydro-electric potential of a million kW.

The station is situated in the Scottish pioneer province of Otago at the lower end of the Roxburgh Gorge, approximately five miles upstream of the town of Roxburgh and about 100 miles by road from Dunedin. The Clutha has a long-term average discharge of about 18,000 cusecs at the site of the works.

History

Its potentialities as a source of hydro-electric power were reported upon as early as 1903, but the large scale of the work involved was beyond what was considered necessary at that time. In 1944 surveys were begun as a basis for developing these resources in full, with particular reference to sites in the Roxburgh Gorge. In August 1948 a comprehensive report on the preliminary investigations was prepared and provided the background for the scheme now carried to fruition.

Excavation of the diversion channel and construction of a temporary village for staff and employees was begun by the Ministry of Works in 1949, using direct labour. In September 1952, as the Ministry could not complete the project early enough with the resources available, a contract of the target-estimate type was let to an overseas firm for the construction of the civil-engineering work. Difficulties led to the abandonment of this contract in 1954 and in May of that year a new schedule-of-rates contract was let.

Topography, Hydrology and Geology

The total catchment area is 6,100 sq. miles. The greater part of this is mountainous glaciated country draining to the lakes Wanaka, Hawea and Wakatipu. Most of the streams which give rise to the Clutha River flow into Lake Wanaka and have their sources at the main divide near Mt. Aspiring and the Haast Pass. Just below the outlet of Lake Wanaka the Clutha receives from the north the overflow of Lake Hawea,

and from the south the Cardrona River. Passing eastwards to the Cromwell basin, the Clutha is joined by the Lindis River and at Cromwell it receives the Kawarau River, which drains Lake Wakatipu and the Shotover and Gibbston basins. From Cromwell the Clutha flows through the Dunstan Gorge to the Manuherikia Valley, where it receives the Fraser river from the north-west and at Alexandra the Manuherikia from the north-east. Immediately below Alexandra the river enters the Roxburgh Gorge, and some twenty miles downstream emerges at the site of the present works. Of the tributaries mentioned, by far the most important are the Kawarau and the Hawea.

As this river system is principally fed by snowfields and glaciers there is a considerable annual range of discharge, with the minimum in late autumn and winter and the maximum in spring and early summer. Gaugings over a 17-year period reveal a mean annual discharge in the gorge 17,650 cusecs, with the monthly average flow dropping below 7,500 cusecs on five occasions during that period at times of winter flow. The highest flood on record is that of 1878, when the discharge at the site of the present works was approximately 117,000 cusecs.

The lake formed by the Roxburgh dam is confined within the steep-sided and rocky gorge, so that very little useful farmland is inundated. At maximum operating level the surface of the lake will be R.L. 430 ft., this limit being imposed by the situation of the town of Alexandra at the upstream end of the gorge.

The country adjoining the dam site is bare and rugged. The basement rock consists of schists of the Otago Central type and is structurally sound. There are minor joint planes and narrow crush-bands in the upper levels, but there are no complex geological features to cause any great engineering difficulties. The geology of the gorge is straightforward, a condition that has rarely been experienced in previous hydro-electric work in New Zealand. The region in which the Clutha basin is situated is one of low seismicity; there are very few active faults and none near the Roxburgh Gorge.

General Description

The dam is of the mass-concrete gravity type, straight in plan over the greater part of its length but with the right abutment and spillway sections angled somewhat downstream to the remainder. The powerhouse is built across the river, along the toe of the dam, with the eight penstocks passing along the downstream face. The spillway section is towards the western end. Water passing over the spillway passes along three long spillway channels which discharge some 560 ft. downstream of the powerhouse centreline. During construction, these spillway channels formed part of

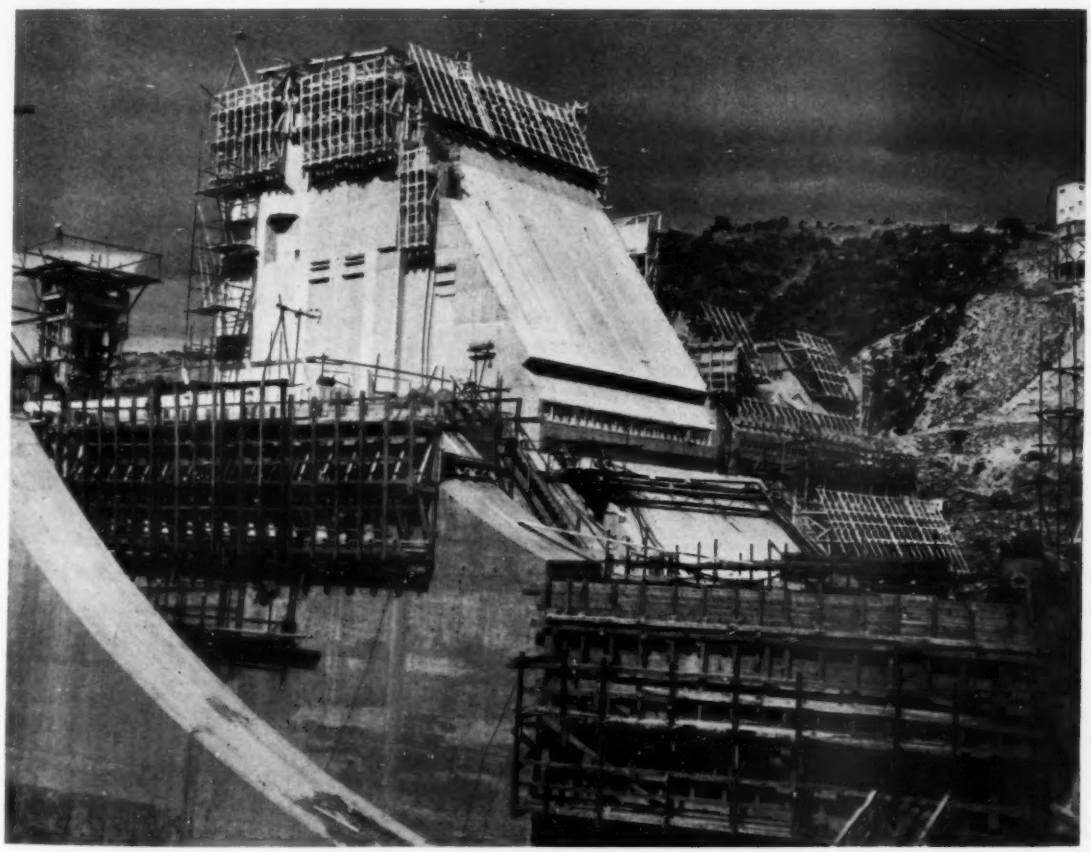


Fig. 2. View of dam from spillway during construction

the diversion channel, the water passing through three sluices in the lower portion of the spillway block. Upstream of the sluices, the diversion channel is an open cut in the rock about 90 ft. wide and 70 ft. deep. The total length of the diversion channel is some 1,500 ft., including the rock cut, sluices and concrete spillway channel sections.

The leading dimensions of the dam are as follow:—

Crest length	1,220 ft.
Height above general rock level near the centre	185 ft.
Height above lowest concrete of the gullet plug	240 ft.
Base width of centre-most blocks	157 ft.
Crest of intake blocks	48 ft.

The dam consists of 24 blocks of which eight are penstock intake blocks and four are in the spillway section. The length of the blocks varies, but generally they are placed at 50 ft. centres and separated by transverse cooling slots 5 ft. in width.

The deck level is R.L. 435 ft. (Clutha datum) or 5 ft. above maximum lake level. The deck carries a road and footways, together with tracks for the 30 ton intake stoplog crane and the screen cleaner. The downstream face of the penstock blocks is battered 7 horizontal to 10 vertical up to R.L. 402·86 ft., above

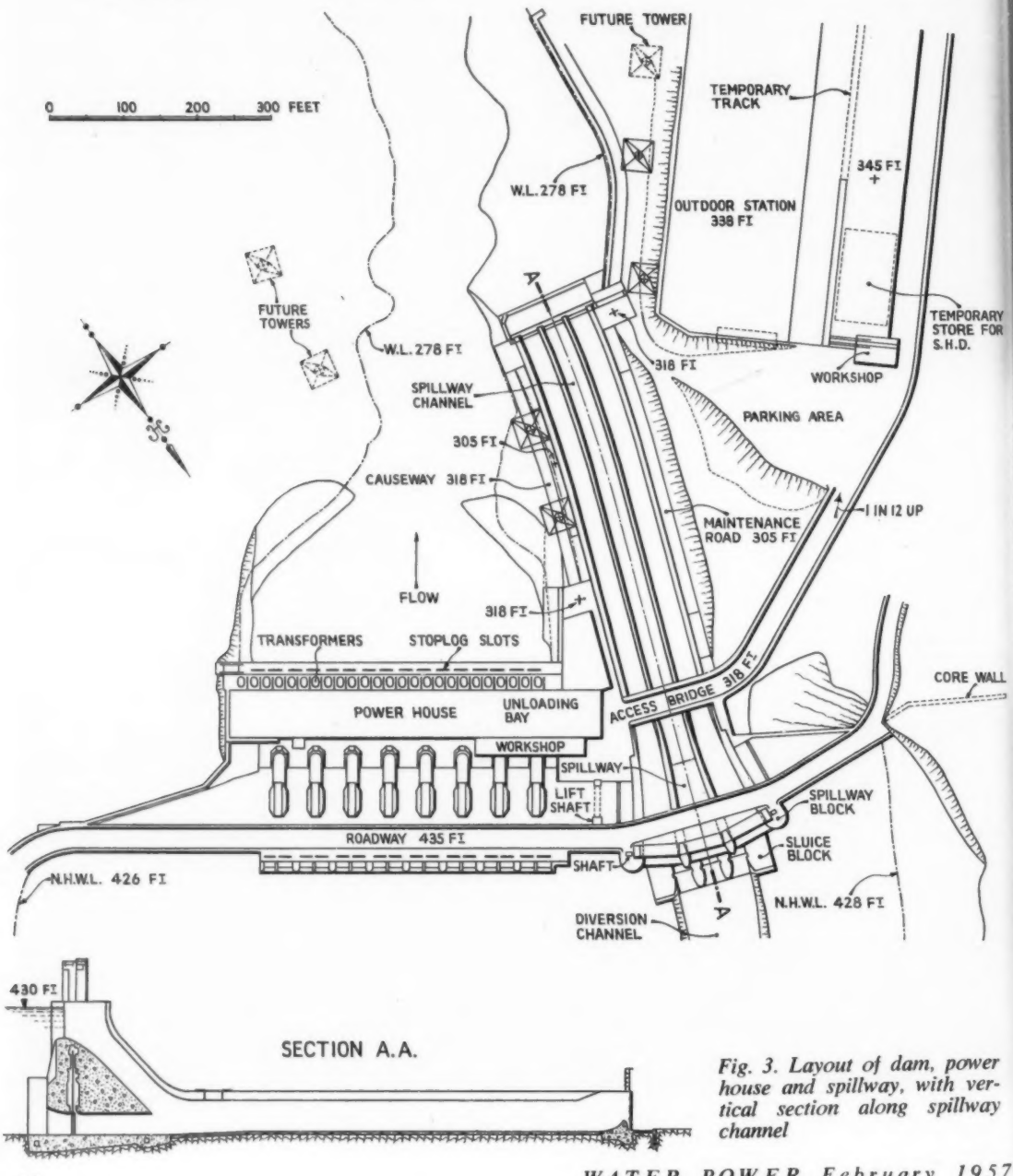


Fig. 3. Layout of dam, power house and spillway, with vertical section along spillway channel

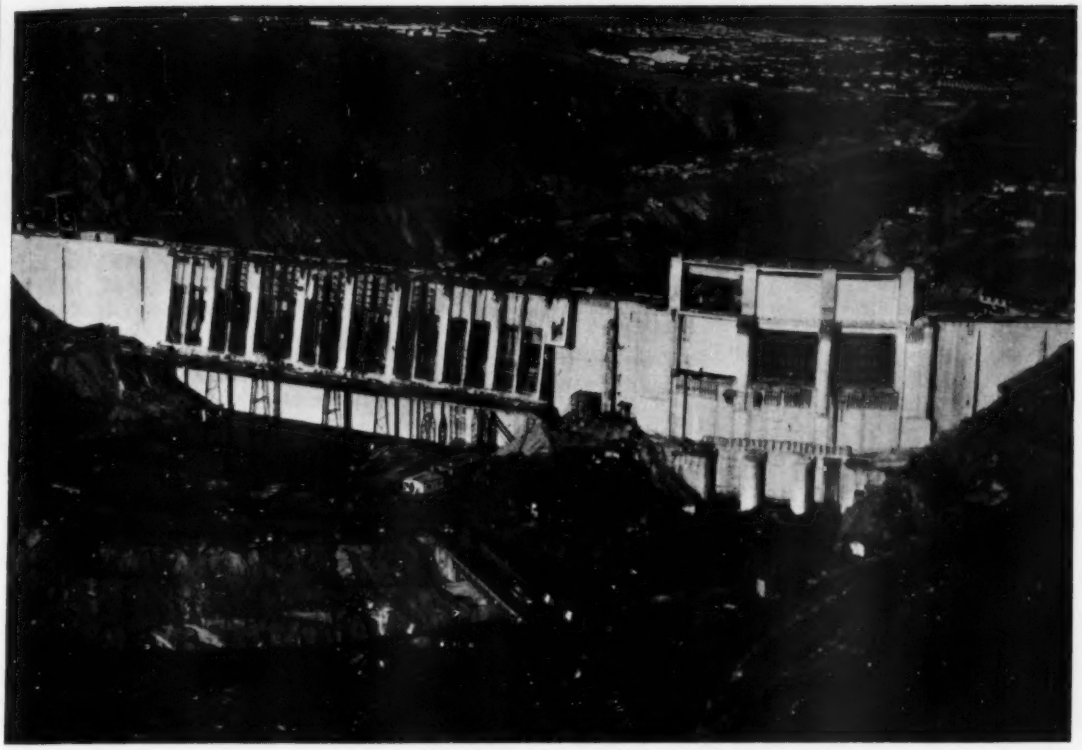


Fig. 4. Upstream face of dam showing intakes and spillway gates

which it is vertical for the remaining height to the footway cantilever soffit near crest level. The remaining blocks, except those of the spillway section, are similarly battered except below R.L. 330 ft. where the batter eases from 7 : 10 to 9 : 10. The upstream face is vertical except at the intakes. The intakes project 18 ft. 3 in. in advance of the vertical face at R.L. 352·30 ft. and the centreline of the penstock intake section is at 379·00 ft. or 51 ft. below maximum lake level.

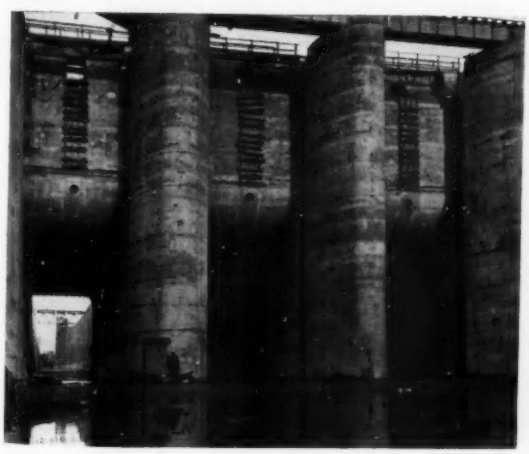


Fig. 5. Sluices before diversion of river

To construct the overhanging slab or soffit above which the intake piers rise, the contractor adopted a precast method of construction. This took the form of a series of cantilevers of inverted T-section, each 4 ft. wide across the flange, with the web tapered in elevation. Each precast beam was 31 ft. long, the necessary overhanging length being 18 ft. 3 in., and the total weight 9·8 tons. The beams were lifted into place by cableway and secured with 1½ in. diameter holding down bolts. The cantilevers thus provided the soffit surface and served in place of both falsework and shuttering. The concrete filling to the invert of the intakes and to the dividing piers was thus placed directly on the precast cantilevers, the webs of which were buried in the mass.

Bar screens are provided at the intakes 42 ft. wide by 80 ft. high and are divided into four panels. The screen cleaner is of the opening rake type.

Stoney roller-type intake gates have been provided, 19 ft. by 18 ft. and weighing 19½ tons each. They are operated by hydraulic lifting cylinders of 12 in. bore and 19 ft. 3 in. stroke, with a working pressure of 600 lb. per sq. in. There are duplicated individual pumping units for each gate. The gates are held open on hydraulic pressure and can be closed by remote control.

The intake stoplogs are of the bulkhead type, their weight being 22 tons. A 30 ton Goliath crane running on the dam deck is provided to handle them as well as the other intake equipment.

"Prepakt" concrete was used around the lower por-

tions of the penstock and intake transition sections to simplify concreting in the confined spaces.

Spillway

Spillway capacity is provided for 150,000 cusecs. It is divided into three sections by reinforced concrete division walls. The crest is at R.L. 388·00 ft. and the division walls extend above this to serve as piers to support the roadway for the bridge. Three spillway gates of the wheel type provide retention up to R.L. 430 ft. They measure 52 ft. by 44 ft. high and weigh 135 tons each. They are fully counter-weighted and are operated by electric winches driving a pair of link chains connecting the gate and counterweights. Alternative hand operation is provided for emergency use. The spillway stoplog is of the floating or caisson type 54 ft. long by 45 ft. high. When not in use as a stoplog, this caisson may be used as a barge for handling the sluice stoplog caisson.

The lower portion of the spillway structure contains three diversion sluices, each 23 ft. 4 in. wide by 28 ft. 6 in. high, with inverts at R.L. 260 ft. The division walls between the sluices are 16 ft. thick and continue downstream of the spillway block to form the division walls between the spillway channels, tapering down to a thinner section immediately downstream of the block.

The diversion openings are closed by three gates, each weighing 80 tons. These are of the Stoney roller face-sealing type and are operated by hydraulic lifting gear situated in galleries and shafts in the block above them. The lifting cylinders have a stroke of 29 ft. 3 in. and a bore of 21½ in. with 740 lb. per sq. in. working pressure. A sluice stoplog of caisson type is provided, generally similar to the spillway stoplog but submersible. Both this and the spillway caisson are moored by swinging arms to the face of the dam.

The downstream ends of the two outer sluices are closed with reinforced concrete slabs to provide a continuous invert from the sloping spillway to the channels.

The spillway channels are provided with deflectors at their outlets and the channels can be closed off, singly or together, by the stoplogs. These are individual welded steel beams handled by a stoplog monorail structure with electric hoists.

Gullet Plug

The gullet in the river bed was approximately 90 ft. wide at the top and had very steep, heavily worn sides extending to roughly 55 ft. below the general rock surface. The concrete was placed in two parts. Cross-walls were built, one each at the upstream and downstream limits of the plug, and one at the junction of the powerhouse and dam. The gullet was thereby divided into two sections, of which the upstream one was filled first. This was done in one continuous pour of concrete containing 15,500 cu. yards, taking 10 days. The concrete mix contained 135 lb. of cement plus 85 lb. of fly-ash per cu. yard, with a maximum aggregate size of 6 in. At the upstream face a richer mix without fly-ash was used and around galleries the maximum aggregate size was 1½ in. Cooling coils were placed at 5 ft. centres in horizontal layers at vertical intervals of 5 ft. This large pour proved very successful and no serious difficulties were met. The temperature of the mass did not exceed 67° F.

The downstream portion of the gullet, requiring 6,500 cu. yards, was filled with "Prepakt" concrete, the lower half having the cement grout injected under water.

Penstocks

The penstocks are of all-welded construction. The shop welding of the sections was carried out by subcontract in a special factory on the site, using the semi-automatic submerged arc process. All welds, both shop and field, were examined by radiography.

The penstocks are 18 ft. internal diameter at the intake, tapering down to 15 ft. at the scroll case. At the intake the plate thickness is ⅜ in., increasing to ⅞ in. at the scroll case, with 1⅛ in. maximum at certain points.

Powerhouse, Workshop, and Control Building

The powerhouse is 504 ft. long by 64 ft. wide. The superstructure consists of welded steel portal frames with precast concrete cladding on walls and roof. The majority of precast wall slabs are 25 ft. long, 3 ft. 3 in.

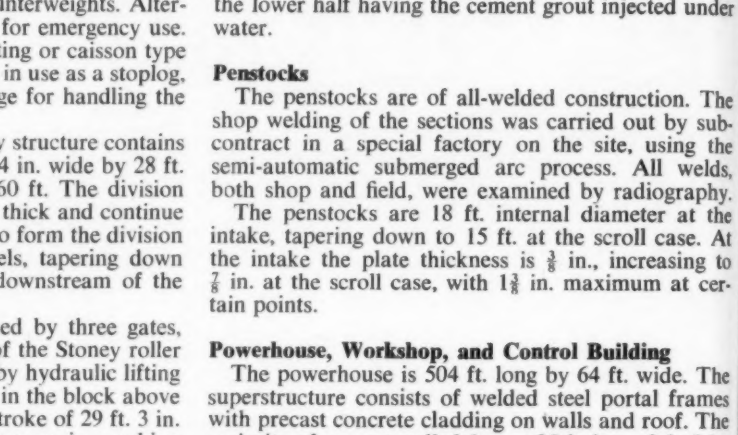


Fig. 6. Spillway block, showing gates and river diversion

deep and 9 in. thick, weighing about 3¼ tons each. The exterior of the precast walls has been finished by grinding to expose the aggregate. Precast slabs and beams also have been used on the curtain wall at the stoplog platform outside the downstream wall of the powerhouse. These slabs are 25 ft. long by 7 ft. 3 in. deep and weigh 8¼ tons each. The substructure is of reinforced concrete.

The draught tubes have an overall width at the outlet of 41 ft. and are provided with a 5 ft. thick dividing wall. The draught tube stoplogs, consisting of welded steel bulkheads in two halves bolted together, are handled by a 10-ton crane running on the stoplog platform. A full set of sixteen stoplogs is provided.

The transformer platform lies between the powerhouse superstructure and the stoplog platform. Blast walls dividing the transformers are constructed of precast components prestressed in position.

Fig. 7. Downstream side of power house

"Prepakt" concrete was again found very useful in filling around the scroll cases in the lower levels of the powerhouse.

Two overhead travelling cranes, each of 118 tons capacity, are provided in the powerhouse to handle permanent equipment.

The workshop building adjoins the powerhouse on the upstream side at the west end, and on the downstream side is the control building which lies between the tailrace and the spillway channel. In addition to the control room this building houses the offices. Access to the powerhouse, workshop and control building is gained by a three-span rigid-frame reinforced-concrete bridge spanning the spillway channels at R.L. 318 ft.

Gates, stoplogs and associated equipment comprise all told: intake gates and stoplog; spillway gates and stoplog; sluice gates and stoplog; draught tube stoplogs; outlet stoplogs.

In the frames for the sluice gates, stainless steel roller tracks have been installed to a tolerance of 0·003 in. and the stainless steel seal frame to a tolerance of $\pm \frac{1}{32}$ in. The rollers are 7¾ in. in diameter and number 74 with 37 in each cage.

The spillway gate wheel tracks are stainless steel of the crowned type, radius 25 ft. and set to a tolerance of 0·010 in. Each spillway gate has four girders, each girder with a pair of dual-wheel bodies. The wheel diameter is 36 in. and the face width 7 in. The wheels are fitted with shrunk stainless steel rims and Lubrite bushings.

The intake gate roller tracks are installed to a tolerance of 0·003 in. These also are stainless steel, as are the rollers which are 4 in. in diameter. There are 52 rollers, 26 in each cage.

All the gates and stoplogs, as well as the inside of the penstocks, are protected by a phenolic resin paint.

Turbines, Generators and Electrical Equipment

Ultimately there will be eight generating sets. They are spaced 58 ft. apart and are serviced by two 118-ton travelling cranes supplied by Cowans Sheldon and Co. Ltd., Carlisle, England. The gantry rails are F B section weighing 112 lb. a yard. A traversing speed of 90 ft. a minute is achieved along the length of the machine hall and a transverse speed of 30 ft. a minute.

The first four turbines are of the vertical Francis type manufactured by the Dominion Engineering Co. Ltd. of Canada and are rated at 56,000 h.p. when running on a head of 148 ft. The guaranteed efficiency is 92·2 per cent. at three-quarter load. Each runner, which has a speed of 136·3 r.p.m., is 12 ft. 10 in. in diameter and has a weight of 83,000 lb. The total flywheel effect of the turbine and shaft is 1,050,000 lb. ft.² and a maximum runaway speed of 252 r.p.m. has been guaranteed.

The generators, supplied by Metropolitan Vickers Electrical Co. Ltd. of England, are rated at 44,444 kVA (40,000 kW at 0·9 power factor) and generate at 11 kV. At full load the guaranteed efficiency is 97·69 per cent, and at three-quarter load 97·36 per cent. The rotating parts of the generator and exciter weigh 395,000 lb. and have a flywheel effect of 29,800,000 lb. ft². The load on the thrust bearing due to the generator parts is 395,000 lb., while the total load amounts to 375 tons.

The limitations set by the transport facilities between the port of Dunedin and Roxburgh made it necessary to split each wound stator for shipment into six equal sections. These were then bolted together on site. Each rotor was despatched from the works almost entirely broken down into its smallest components, and built up on site.

The stator winding is of the double layer lap type, the insulation being bitumen bonded mica with Haefely tube over the slot portion. To reduce eddy currents, one turn in each coil is given a Roebel transposition outside the slot. Anti-condensation heaters are provided as usual.

The only portions of the generators which are visible above the operating floor of the generator hall are the main and pilot exciters, also the governor

generators. The nine feet high stators are each accommodated in a 32 ft. square concrete pit, twin air coolers bolted to the stator frame being located at each corner of the square. Fans mounted above and below the generator rotor circulate air inside the machine and through the coolers at the rate of 70,000 cu. ft. per min.; up to 10 per cent. of this can be bypassed into the station for space heating during cold weather.

To deal with the possible incidence of fire within the stator of any generator, BTH supplied two batteries of fifteen 80 lb. cylinders of CO_2. One battery is arranged to provide the initial discharge, operated automatically by either the circulating current protection or by thermostats in the hot air stream, also manually by push-button. The other battery provides an extended discharge, should this be required, and can only be operated by independent push-button.

Water for the air cooler is circulated at the rate of 800 g.p.m., the pressure being kept below 20 lb. per sq. in. The braking time for the rotor from half speed is about five minutes.

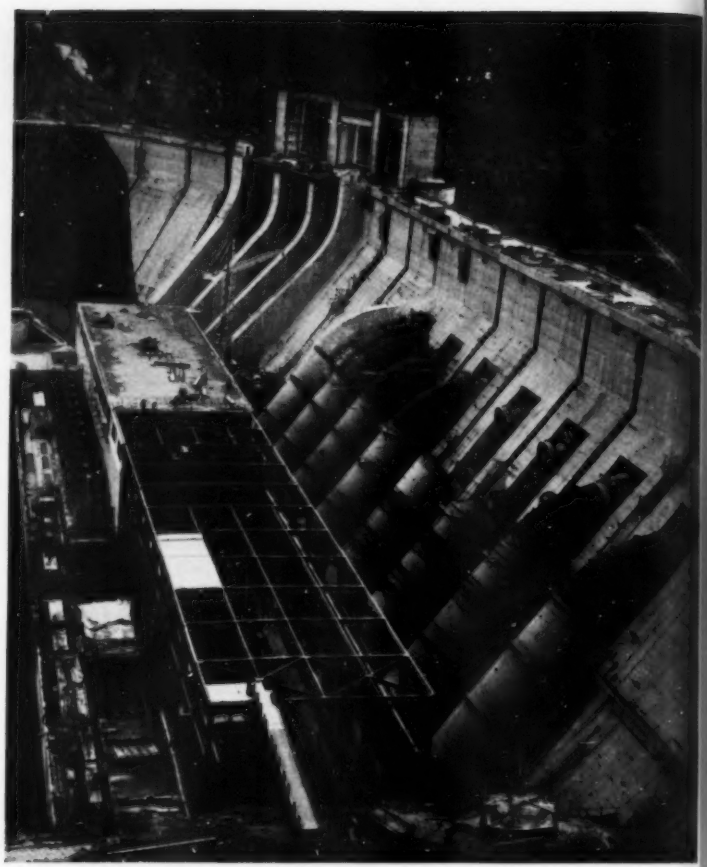
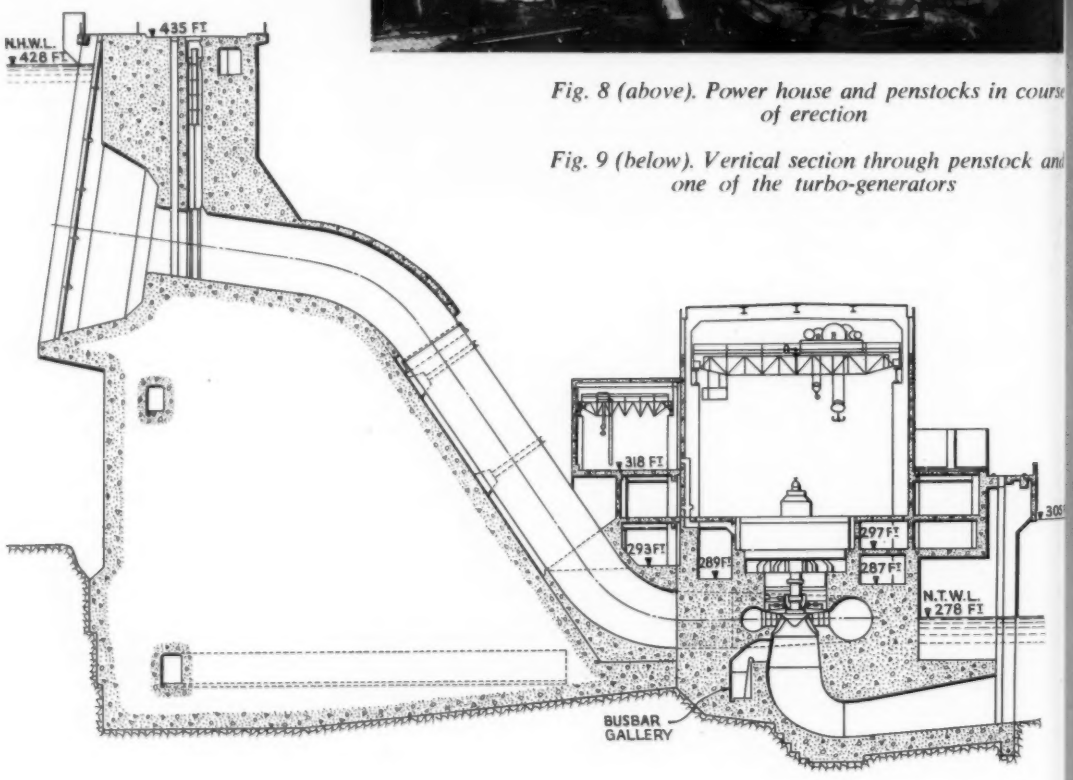


Fig. 8 (above). Power house and penstocks in course of erection

Fig. 9 (below). Vertical section through penstock and one of the turbo-generators



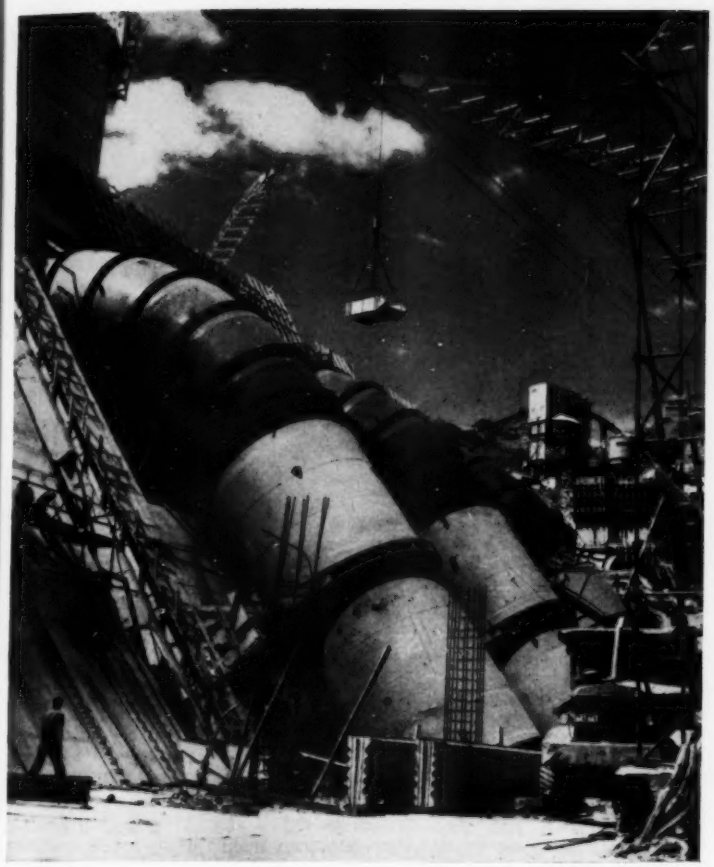


Fig. 10. Nos. 1, 2 and 3 penstocks during erection

There are four banks of transformers each having a capacity of 44,400 kVA and stepping up from 11,000 to 220,000 V. A spare single unit is also provided. This equipment was supplied by Ferranti Limited, England. All these units operate on water-cooled forced-oil circulation.

Concrete

The total volume of concrete in the works exceeds 700,000 cu. yards. Cement was obtained from the Milburn cement works near Dunedin from where it was hauled by rail in bulk to the railhead at Roxburgh. Here it was loaded into bulk tank wagons for haulage to the site. Unloading from the tank wagons to the cement silo and from the silo to the batching plant was done by mechanical conveyor. Aggregate was conveniently obtained from an extensive deposit of river shingle and sand about a mile downstream of the site. The material is waterworn greywacke river shingle. No crushing was required. The material as dug was screened to the required range of sizes from 6 in. to sand. After screening, the aggregate was hauled by lorry to the batching plant and there stockpiled as follows: 6 in.-3 in.; 3 in.-1½ in.; 1½ in.-¾ in.; ¼ in.-⅜ in.; ⅜ in.-$\frac{3}{16}$ in.; sand.

Eight standard concrete mixes were specified, with cement contents ranging from 250 lb. to 450 lb. per cu. yard; maximum water : cement ratios ranged from 0·50 to 0·75 and maximum aggregate sizes of 6 in., 3 in., 1½ in., ¾ in., depending upon the nature of the work. The bulk of the concrete has, however, been of four types, three for mass and one for reinforced concrete with maximum water : cement ratios of 0·50 to 0·65.

Most of the concrete was handled by the cableways in 4 cu. yard hopper-bottom buckets and placed with the aid of heavy vibration. Air-entrainment was universal. Fly-ash was used in certain bulk pours (e.g. the gullet) and in grout for "Prepakt" concrete.

Pumped concrete was used in the very early stages by the Ministry of Works when constructing the spillway channel side walls. It has again been used recently by the contractor principally for slot filling and for lining drives. The leanest mix used when pumping had a cement content of 400 lb. per cu. yard, with a water : cement ratio averaging 0·58 maximum and a maximum aggregate size of 1½ in.

Care has been taken to ensure a good standard of concrete surface finishing. Steel sheathing is used on large faces of the dam except at the intakes where a better finish is required. Here, and for reinforced concrete walls in the power house, either close fitted dressed timber or plywood facing was commonly used.

Faces subject to high velocity water flow were formed with shuttering having an absorbent lining, or, in some cases with plywood-faced or dressed-timber shuttering, special care being taken to eliminate pitting. Grinding was used where necessary to eliminate abrupt irregularities on faces where a good finish is required. Unformed surfaces subject to water flow were finished to a high standard of accuracy and smoothness by mechanical steel trowelling. The same method was adopted for finishing concrete floor toppings.

Concrete Cooling

Approximately 650,000 ft. of cooling coil have been used in the mass concrete sections of the work. For control of cooling in dam blocks, three cooling zones are defined as follows:—

Zone 1: Zone of high restraint extending 20 ft. above rock level in which cooling pipes are spaced at 2 ft. 6 in. horizontal centres, with lifts of 2½ ft. and 5 ft., depending on the placing temperature.

Zone 2: Zone requiring forced cooling, but not a zone of high restraint, and requiring generally a 5 ft. spacing of pipes and 5 ft. lifts.

Zone 3: Zone not requiring forced cooling to control stresses.

The two aims of cooling were first, to keep the peak

temperature after setting within prescribed limits, and second, to reduce block temperatures for slot filling. In zones of restraint the heat rise was generally not permitted to exceed 80°F., and elsewhere 100° F. Before slots could be filled the mass concrete temperature was reduced to, or preferably below, 50°F., which is approximately the mean annual air temperature at the site. Measurement of temperatures was mainly by copper-constantan thermo-couples, placed in the centres of lifts. Cooling was effected by the circulation of river water, or by chilled water when necessary. Coils were grouted up after use. Some will serve also as part of the earthing system for the generating plant.

Drilling and Grouting

Diamond drilling, with core extraction, was used for the exploratory work, the holes ranging from 3 in. to 1½ in. diameter. The grout holes, also 1½ in. diameter, were similarly driven by diamond drills, but the very early investigational work was done with a cable percussion rig.

Consolidation grouting has been carried out under the dam, the spillway block, the spillway channel and the powerhouse foundations, extending 20 ft. into rock. Generally a 10 ft. grid was used, built up on a primary, secondary, and tertiary basis as required, but according to site conditions spacings down to 5 ft. and less, and up to 20 ft. have been used. Of this drilling, some was by wagon drill, and the balance by diamond drill. Stage grouting was mainly employed for the consolidation holes, with pressures varying from 15 lb. per sq. in. at the top to a maximum of 60 lb. per sq. in. at the bottom of the tertiary holes.

The deep grout curtain beneath the dam and spillway block extends approximately 100 ft. into the rock, reaching R.L. 90 ft. in the lowest part at the gullet. Part of the curtain was stage grouted and part stop grouted, with a maximum pressure of 120 lb. per sq. in. Where there was insufficient weight of concrete overhead, the pressure in the top stage was limited to 45 lb. per sq. in. Later, when the height of the concrete was adequate, a grout pressure of 120 lb. per sq. in. was used for all stages. Initially stage grouting was used as specified, but subsequently stop grouting was adopted. Stage grouting was reverted to in poorer ground surrounding the gullet, after difficulty had been experienced with the packers.

Shallow grout curtains extending 20 ft. into the rock circuit the powerhouse perimeter and are carried along the causeway embankment dividing the spillway channel from the tailrace.

Excavation

The final quantity of excavation amounts approximately to 550,000 cu. yards and comprises:—

Diversion cut and spillway channel, including dumplings	225,000
River gullet below R.L. 250 ft.	22,000
Main area of dam, powerhouse and tailrace	180,000
Outlet area below spillway channels	34,000
Outdoor station area	29,000
Roads, etc.	30,000
Total	520,000

The cofferdams contain the following quantities of fill:—

Upstream cofferdam (cu. yards)	226,000
Downstream cofferdam (cu. yards)	57,000

Construction Plant and Installations

The central concrete mixing plant was supplied with aggregate from a stockpile storage system which received the sized material from the aggregate washing and screening plant. The material was placed in the bins by a system of inclined and horizontal distribution belt conveyors.

Weighbatching was semi-automatic with a weighing hopper for each size of stone. A visual and graphic record of the weight of each component of each mix was recorded on the control panel.

Mixing was carried out in four tilting-drum mixers of 2 cu. yard capacity each; these mixers discharged into buckets which were transferred to the cableway pick-up point by means of trucks hauled by diesel locomotives.

In addition to the main Johnson batching plant a Stothert & Pitt plant of one cu. yard capacity was installed. In the early stages of the job a Winget mixer with two one-yard drums, and a Rex one-yard plant, were in use.

Cableways

The two travelling cableways had a span of 1,605 ft. and a normal safe working load of 10 tons each. Each is operated by two 200 h.p. electric motors, the hoist and travel drums being so

Fig. 11. Scroll case for No. 2 machine, ready for welding

Fig. 12. Aerial view of Roxburgh dam and power station after closure of sluices

arranged that both motions may be operated simultaneously.

Lake Control

To ensure full economic development of the Clutha River power potential, control at the lakes is necessary to provide storage for use during the low-flow periods in winter. At the outlet of Lake Hawea extensive control works are being built, consisting of an earth dam and concrete sluice structures, with the object of raising the water level by 60 ft. At the outlet of lake Wakatipu the existing Kawarau gates will suffice to control the discharge from that lake, as the situation of Queenstown prohibits a further increase in the level of the lake.

Conclusion and Acknowledgments

The station was constructed for the New Zealand Government. Civil engineering investigation and design were carried out by the Hydro-electric Design Office of the Ministry of Works and civil engineering construction is under the direction of the Ministry of Works. Specification of the electrical installations and machines was the direct responsibility of the State Hydro-Electric Department, who are also carrying out the installation with their own forces. The civil engineering construction has been mainly carried out by contract.

The control works at Lake Hawea are being designed and constructed by the Ministry of Works. Including the transmission of power and the Lake Hawea control works, the approximate overall cost of the scheme will be about £30,000,000.

The contractors for the building of the dam, spillway, powerhouse and subsidiary structures were Holland & Hannen and Cubitts Limited in association with Conrad Zschokke S.A., of Switzerland. These two firms became associated in September 1952, at which time the engineers of the Ministry of Works remained on the job in a supervisory capacity. The contractors encountered unexpected problems and conditions, and by arrangement with the Government of New Zealand, the firm of Downer & Co. Ltd. was brought into the scheme, also in association with the Cubitts-Zschokke combination. Downer & Co. Ltd. completed the Waitaki power station extensions and also, in association with Morrison & Knudsen, of U.S.A., successfully carried out the Rimutako railway and tunnel contracts.

This article is published with the permission of the Engineer-in-Chief of the New Zealand Ministry of Works, through whose courtesy most of the material was obtained. The information was largely compiled by A. G. Fellows, Engineer, Ministry of Works, Roxburgh, under the supervision of A. J. Learmonth, Project Engineer.

The Economics of Pumped Storage

In this article Dr. Charles Jaeger discusses the general trend of power generation and shows how pumped storage systems, the economics of which he analyses, are likely to play an increasingly important part in meeting peak loads

PART ONE

THE prediction of electric power requirements is based in most countries on a detailed analysis of the power market. For investigations of a more general nature it is often assumed that the demand for electric power roughly doubles every ten years, and this assumption is proved to be sufficiently accurate by Fig. 1 taken from Paper No. 173, E/ECE/EP United Nations, Economic Commission for Europe, Nov. 12, 1955[1, 2]*. The extrapolation of this curve over the next period of ten years (1956-1966) implicity assumes far-reaching social and technical changes to occur during this period, compelling us to adopt an entirely new approach to the problem of energy production.

A recent paper by R. Gibrat and F. Auroy[3] shows the magnitude of the problems involved. According to this paper, Electricité de France—in order to close the future gap between power demand and energy production—have decided to start with the immediate construction of the Rance tidal-power scheme. They also feel compelled to carry out serious investigations into the enormous Chausey Island tidal scheme, which would add some 10 to 15 million horsepower to the French Grid.

According to detailed studies made by M. A. Winiger, Electrowatt, Zurich, it is expected that Switzerland will have exhausted their water-power resources before nuclear power will be able to take over on a large scale[4]. France and Switzerland still possess large hydro-power resources, and these are expected to be exhausted in about 15 years.

The anxiety expressed by leading engineers regarding the immediate future of the power economy of European nations is characteristic of the present-day position. On more general lines, the conclusions reached by the Organisation for European Economic Co-operation, Commission for Energy, are very similar. They foresee a widening gap in the coal production which in 1975 would reach several hundred million tons for Western Europe alone[5].

A block of population of about 50 million people with Western European standards of living will probably require an additional capacity of about 8 to 10 million kW in the course of the next ten years, providing for an additional energy production of 30 milliard kWh per year at the end of that ten-year period. Whatever the source for the base load, be it coal-produced thermal energy, nuclear energy (still in its early stages), base-load hydro-power, or tidal energy, peak-load capacity will have to be installed corresponding to about a quarter or a third of the total capacity increase.

The feeling is spreading among power engineers that pumped storage may well be the answer to some of the problems arising out of the requirements for additional peak capacity. Pumped storage does not create energy; it merely transforms base-load (night) energy or summer energy into more valuable peak (day-load) or into winter energy. This process will prove in future to be essential for the energy balance of many countries.

Table I* shows how pumped storage has developed during recent years; this general trend is expected to become more pronounced in the future.

Messrs. T. G. N. Haldane and P. L. Blackstone have analysed the economics of a pumped-storage scheme connected to a grid largely, if not exclusively, fed by thermal power. The basic idea in this analysis is that the thermal energy required for pumping will be produced by the more out-of-date thermal units

* Partly based on a paper by Mr. G. V. Newman published in the BEAMA Journal, London, Vol. 63, No. 2, May 1956.

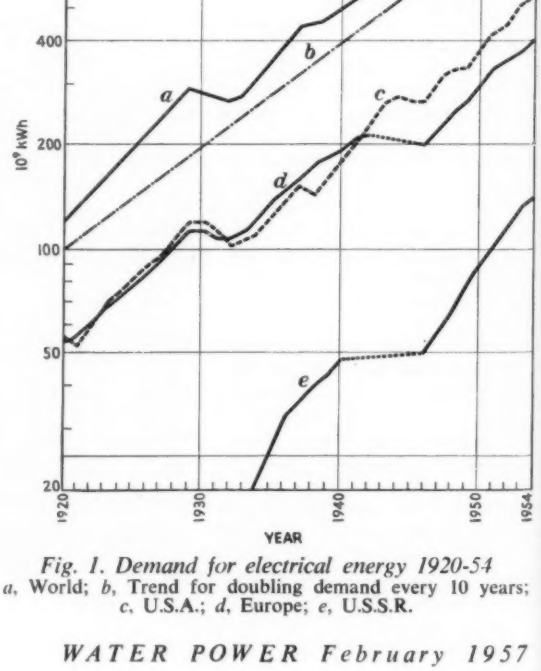


Fig. 1. Demand for electrical energy 1920-54
a, World; *b*, Trend for doubling demand every 10 years; *c*, U.S.A.; *d*, Europe; *e*, U.S.S.R.

* The figures in brackets refer to the Bibliography.

TABLE I—IMPORTANT PUMPED STORAGE SCHEMES AT PRESENT IN OPERATION OR UNDER CONSTRUCTION

Station	Country	Generating capacity kW	Pumping capacity h.p.	Pump delivery	Max. head	Date of initial operation
Niederwartha ...	Germany	4 × 22,000	4 × 27,000	504	154	—
Bleiloch	,,	2 × 21,300	1 × 24,000 1 × 14,500	185	56	—
Herdecke	,,	4 × 35,000	4 × 36,000	540	165	1930
Haerrsern	,,	4 × 35,000	4 × 28,000	720	220	1930
Witznau	,,	4 × 60,000	4 × 39,000	895	273	1943
Waldshut	,,	4 × 35,200	4 × 24,000	535	163	1951
Wäggital (Rempen)	Switzerland	4 × 14,000	4 × 5,700	845	258	1924
Tremorgio	,,	1 × 11,000	2 × 6,400	3000	914	1926
Oberems	,,	2 × 4,000	1 × 7,200	3304	1007	1942
Etzel	,,	6 × 16,000	2 × 21,500	1611	491	1947
Grimsel-Oberaar	,,	1 × 31,000	1 × 24,750	1312	400	1954
Lac Noir	France	4 × 30,000	3 × 27,000 1 × 17,000	420	128	1934
Pragnères-Glaire	,,	—	1 × 3,000	460	140	1953
Pragnères	,,	2 × 73,000	1 × 7,000	1310	400	1953
			4 × 14,000	1310	400	1953
Our	Luxemburg	4 × 80,000	4 × 53,750	920	280	constr.
Cotilia	Italy	2 × 30,000	2 × 37,600	500	152	1942
Provvidenza	,,	3 × 50,000	2 × 61,600	940	287	1950
Ill-Rodund	Austria	4 × 42,500	??	1130	383	1952
Ill-Lünersee	,,	6 × 36,200	6 × 57,500	3200	978	constr.
Limberg	,,	2 × 55,000	2 × 85,000	1500	457	1955
Reisseck	,,	??	3 × 7,550	3510	1070	constr.
Flatiron	U.S.A.	1 × 8,500	1 × 13,000	300	91	1954
Hiwassee	,,	1 × 56,000	1 × 102,000	205	62	constr.
Niagara	Canada	6 × 34,500	6 × 46,000	90	27	constr.
Sron Mor (Glen Shira)	Great Britain	1 × 5,000	1 × 7,000	160	49	constr.
Ffestiniog	,,	4 × 75,000	4 × 83,000	1070	326	constr.

being maintained on the grid for the purpose of producing energy at low load factor. In these circumstances there is very little difference between the value of the off-peak energy (0·45 to 0·46d. per kWh) and the value of on-peak energy (0·65d. per kWh), the ratio being 1 to 1·44 instead of 1 : 2 or even 1 : 3 assumed on grids fed by run-of-river hydraulic power stations. The economics of the assumed power station (generating capacity 200 MW and pumping capacity 268,000 h.p.) investigated by these authors are mainly based on the value of the power estimated at £4 per kW. When introducing the correct efficiency factors, it is seen that "every kWh generated represents in this particular example a financial loss." The scheme as a whole is stated to be a paying proposition because of the value of the installed capacity.

This analysis is particularly valuable inasmuch as it shows some aspects of the economics of pumped storage in a grid mainly fed by thermal (coal generated) energy. In fact the Central Electricity Authority (C.E.A.) are going energetically ahead with the Ffestiniog pumped-storage scheme in Wales. Luxemburg, too, is now building the River Our pumpage scheme, surrounded as it is by coal mines in the Saar and in the Ruhr.

It is likely that in the near future the necessity of developing pumped storage will impose itself far more drastically, as there is often no other alternative to peak-load power. The demand for peak capacity will rapidly grow beyond the figures considered in the example developed by Messrs. Haldane and Blackstone; in fact, the required pumped-storage capacity will be of the same order as the nuclear-power capacity, which is roughly estimated at 2,000 to 2,500 MW for the next ten years in Great Britain alone. The pumped storage will then no more have the character of a standby for emergency cases, to be fed by the dearest possible steam aggregate, but will have to produce real kWh at a reasonable price. The pumping energy will then be partly excess energy generated by reactors at night, the value of which will have to be low.

The trend towards pumped storage will be accentuated by the growing scarcity of coal, by the tendency of coal prices to rise more rapidly than the general cost of living, and—for the countries of the sterling area—by the dollar situation, since every ton of coal bought outside this area has its equivalent dollar value on the import market.

Figs. 2a and 2b, from a paper by Prof. B. Bauer[7] based on figures published at the Geneva Conference for the Peaceful Use of Atomic Energy, show the present-day position in the relative cost of atomic and thermal power and energy. It is essential to note that these estimates are based on a load factor of 0·8, which means that the power has to be generated as base load.

Different Types of Pumped-Storage Stations

Pumped-storage stations must be adapted to the local conditions as given by the contour lines, the possibility of designing two reservoirs of convenient capacity at convenient levels, and finally by the hydrologic conditions. A true pumped-storage scheme is a scheme where the total amount of water passing through the turbines is equal to the total amount of pumped water, the turbine and the pump working

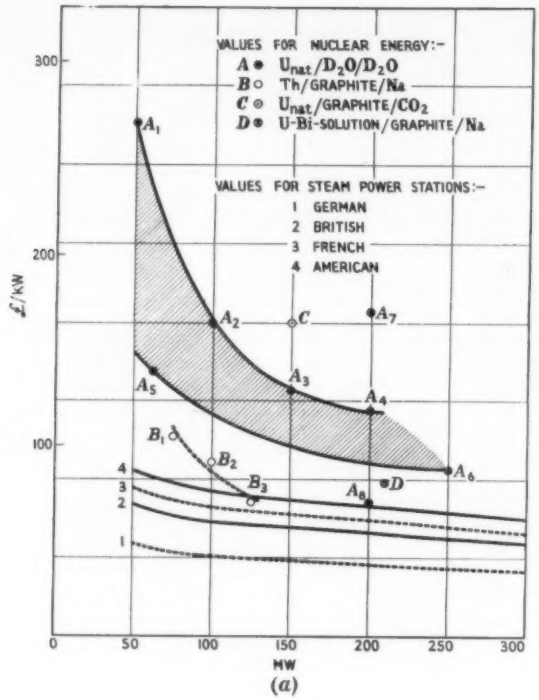


Fig. 2

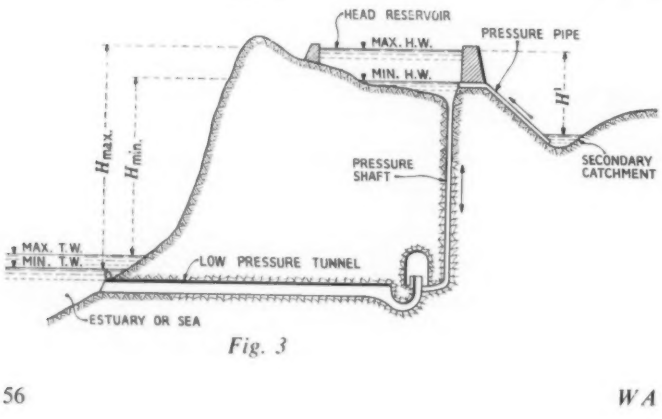


Fig. 3

under the same gross head. The Ffestiniog scheme in Wales and the Lac Blanc-Lac Noir scheme in France are true pumped-storage schemes of this kind.

A mixed pumped storage is a scheme where either the water passing through the turbine is more than the pumped water, and/or where the turbine gross head is more than the pump gross head. Many possible alternatives have been described: the Glen Shira scheme (Clachan) in Scotland is a typical mixed pumped-storage scheme.

Depending on size and function, a storage scheme can be a daily or weekly storage or a seasonal (yearly) storage. Particularly interesting conditions occur when an existing power station, having run for years and paying its way by working on conventional lines, can be extended by building in a pumped storage with little additional losses and at low cost. The economics of such a case will be analysed later.

A pumped-storage scheme requires two reservoirs, and the capacity of the scheme is mainly determined by the useful volume of the smaller of these reservoirs. A substantial economy will be realised if one of the two reservoirs is given by natural conditions. Fig. 3 shows an arrangement where the lower reservoir is either the sea or an estuary, the higher reservoir being built on a coastal ridge. More details will be given when describing some more-important pumped-storage schemes.

Capacity of Plant and Volume of Reservoir

Let us assume that a base-load capacity N_b is being installed; this may be a coal-fired steam turbine, or a nuclear, or a tidal-power station. The load factor of the system is supposed to be α_o. A pumped-storage scheme with an installed turbine capacity N_T is producing the corresponding peak-load capacity. The total capacity of the system is

$$N = N_T + N_b$$

If T_o is the base period (say one day) to which the cycle refers and t_T the time during which the turbines are supposed to run at full load, Fig. 4 yields

$$T_o N_b + t_T N_T = \alpha_o T_o N = \alpha_o T_o N_b + \alpha_o T_o N_T$$

or

$$N_T = \frac{(1 - \alpha_o) T_o}{\alpha_o T_o - t_T} N_b = \frac{(1 - \alpha_o) T_o}{T_o - t_T} N \qquad \ldots(1)$$

and

$$N_b = \frac{\alpha_o T_o - t_T}{T_o - t_T} N \qquad \ldots(2)$$

Table II gives the ratio N_T/N_b and N_b/N for varying values α_o and t_T assuming $T_o = 24$ hours.

If 100 MW of base load (N_b) are being installed, about 30 to 40 MW peak load (N_T) are required to adapt the power production to the demand, assuming a high load factor α_o for the new block of power to be produced.*

Assuming that η_T and η_P are the efficiences of the turbine and the pump, then $N_T t_T/\eta_T \eta_P$ is the energy required by the pumps to feed the peak-load installation, or, if expressed in per cent. of the base-load energy $N_b T_o$:

$$\rho_o = \frac{N_T t_T}{\eta_T \eta_P N_b T_o} \qquad \ldots(3)$$

* The load factor of the whole grid will probably be far less than α_o.

TABLE II
VALUES OF N_T/N_b AND N_b/N FOR VARYING VALUES OF α_o AND t_T

	α_o	0·70	0·75	0·80	0·85
$t_T = 3$ h.	N_T/N_b	0·522	0·4	0·297	0·206
	N_b/N	0·66	0·716	0·771	0·83
$t_T = 4$ h.	N_T/N_b	0·562	0·429	0·315	0·22
	N_b/N	0·643	0·70	0·763	0·822

For $N_T/N_b = 0{\cdot}3$, $T_o = 24$ hours, $t_T = 3$ hours (corresponding to a design load factor $\alpha^1 = 3/24 = 0{\cdot}125$) and $\eta_T\eta_P = 0{\cdot}65$.

$\rho_o = \dfrac{0{\cdot}3}{0{\cdot}65} \cdot \dfrac{3}{24} = 0{\cdot}058$, or 5·8 per cent. of the base-load energy. If the pumping is spread over 6 hours, the power absorbed will be 23 per cent. of the constant-load power.

These figures give roughly the proportion of peak-load capacity to be installed and the amount of off-peak energy required by the pumped storage.

The values for α_o and t_T can be varied according to conditions, but roughly the conclusions concerning the peak-load capacity to be installed and the off-peak energy required will not vary substantially. Whatever the approach, it can be shown that the cost of the energy wanted for pumping the required volume of water is not a factor which can upset the energy price balance on a national scale.

The required storage capacity V is given by the formula (metric system)

$$V = Q \times 3{,}600\, t_T \qquad \ldots(4)$$

As $N = \dfrac{1{,}000\eta_T Q H}{75}$ in h.p. (metric), V is also given by:

$$V = \frac{270 t_T}{\eta_T H} N \qquad \ldots(5)$$

Q is the discharge in metric tons per second, H the head in metres, and N the power in metric horsepower. Tables III and IV refer to formulae (4) and (5).

In order to show the potentialities of existing reservoirs, a comparison with Loch Sloy reservoir is instructive. This reservoir has a capacity of 1,200 million cu. ft. or 34 million cu. m. The head is 910 ft. or 277 m. gross. In order to install there 2 million horsepower (1,470 MW) stored capacity, a volume ($t_T =$ 3 hours, $\eta_T = 0{\cdot}80$).

$$V = \frac{270 \times 3 \times 2 \times 10^6}{0{\cdot}80 \times 277}$$

$$= 7{\cdot}3 \times 10^6 \text{ cu. m.}$$

is required or about $\frac{1}{5}$ of the available volume. This would probably be sufficient to provide peak power for about 4,000 to 5,000 MW base load and would still allow for the reservoir to work as a long-period storage reservoir for normal inflow from the natural and artificial catchment areas.

For heads $H > 100$ m. the volume of storage reservoir required is relatively small, requiring dams which are small compared with ordinary reservoirs storing water over several weeks or several months.

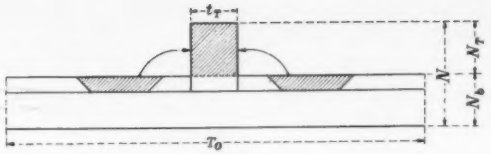


Fig. 4

If, on a particular site, the construction of a huge dam proves to be expensive, capacity could sometimes be obtained at less expense by installing pump-turbine sets and a pumped-storage reservoir.

Remarks on the Economics of Pumped Storage

The following analysis of pumped storage is kept on very general lines, quite independent of the conditions prevailing in the grid. The base load can be steam power, run-of-river power, tidal, or nuclear power. It can be shown that the overall efficiency of a pumped-storage scheme is given by the formula:

$$\rho_1 = \frac{E_T}{E_P} = \frac{H_T Q_T t_T}{H_P Q_P t_P}\, \eta_T \eta_P \qquad \ldots(6)$$

where: H = gross head
Q = maximum discharge
t = time during which the station is loaded at full capacity over a period of one year or one day
$Qt = V$ = total volume of water passing through the runner
E = the energy in kWh per annum or per day
η = an overall efficiency factor including pipe losses.

The index P refers to pumps, the index T to turbines. The efficiency factor $\eta = \eta' \eta''$ where η' is the combined efficiency factor of turbines, generators and transformers and η'' the efficiency of the water ducts (tunnels and pipes).

True pumped storage corresponds to the conditions $V_P = V_T$ and $H_P = H_T$, and therefore $\rho_1 = \rho_1{}^* = \eta_T\eta_P$ (Example Ffestiniog Project, Wales).

Assuming the pipes and tunnels to be short so that the friction losses can be neglected, the value $\rho_1{}^* = \eta_T\eta_P = \eta'_T\eta'_P$ is then equal to the product of the efficiency of the turbines η'_T and of the pumps η'_P. For true pumped storage, when the pipe and tunnel losses are being neglected, a factor $\rho_1{}^* = \eta'_T\eta'_P = 0{\cdot}6 - 0{\cdot}7$ can be assumed.

TABLE III.—STORAGE VOLUME V IN CU. M. FOR A DISCHARGE Q IN CU. M. PER SEC. AND A PEAK-LOAD DURATION t_T IN HOURS

Q	1	10	20	50	100	200	500
$t_T = 1$ h	3·600	36·000	72·000	180·000	360·000	720·000	1,800·000
3 h	10·800	108·000	216·000	540·000	1,080·000	2,160·000	5,400·000
4 h	14·400	144·000	288·000	720·000	1,440·000	2,880·000	7,200·000
5 h	18·000	180·000	360·000	900·000	1,800·000	3,600·000	9,000·000

TABLE IV.—STORAGE VOLUME V IN CU. M. VERSUS THE INSTALLED CAPACITY N (IN METRIC H.P.) FOR $\eta_T = 0{\cdot}75$ AND $t_T = 3$ HOURS AND VARYING HEAD H IN METRES ($V = 1080\ N/H$)

N	10·000	50·000	100·000	150·000	200·000	300·000	500·000
$H =$ 30	360·000	1,800·000	3,600·000	5,400·000	7,200·000	10,800·000	18,000·000
50	216·000	1,080·000	2,160·000	3,240·000	4,320·000	6,480·000	10,800·000
100	108·000	540·000	1,080·000	1,620·000	2,160·000	3,240·000	5,400·000
200	54·000	270·000	540·000	810·000	1,080·000	1,620·000	2,700·000
300	36·000	180·000	360·000	540·000	720·000	1,080·000	1,800·000
500	21·600	108·000	216·000	324·000	432·000	648·000	1,080·000

Mixed pumped storage corresponds to the case where $H_T > H_P$ and/or $V_T > V_P$.

$$\text{Let } \rho_2 = \frac{P_{peak}}{P_{off}} = \frac{\text{Value of on-peak energy in pence per kW}}{\text{Value of off-peak energy in pence per kW}} \qquad \ldots(7)$$

The P_{peak} value, in this formula, should include the value of the power (normally given in £ per kW) expressed in pence per kWh. The simplified expression

$$\rho_2 \rho_1 \geqslant 1 \qquad \ldots(8)$$

represents the condition for a pumped-storage scheme to be economical, provided capital charges and operation costs are being neglected. This condition would approximately apply when an existing power station, having efficiently run for years, was extended into a pumped-storage scheme by installing pumps. Dam, reservoir, tunnels and pipelines are supposed to be paid off by running the station on conventional lines; the additional cost of installing pumps can then be neglected, too.

In a more general case the correct coefficient to be considered would be

$$\rho_2^* = \frac{P_{peak} - P_{charges}}{P_{off}} = \frac{\text{Value of on-peak energy} - (\text{capital charges} + \text{operation charges})}{\text{Value of off-peak energy}} \qquad \ldots(9)$$

The more general conditions for a true or a mixed pumped-storage scheme to be economical are then:

$$\rho_2^* \rho_1^* \geqslant 1 \text{ or } \rho_2^* \rho_1 \geqslant 1 \qquad \ldots(10)$$

Capital charges, operation charges and all types of losses are included in ρ_2^* and ρ_1^*.

A slightly different approach is given by Musil[12]. Let:

V^* = the useful volume of the reservoir, measured in kWh

β_v = yearly factor including interest rates and relative maintenance and operation charges.

c_v = capital cost in £ per kWh of reservoir energy

For an ordinary reservoir to be economical:

$$\beta_v c_v V^* < m N_v + n E_v \qquad \ldots(11)$$

where all the values are in £ per year.

N_v = the installed capacity (kW)

E_v = the yearly energy (kWh) produced by the reservoir

n and m = the convenient price conversion factors.

Let $E_v/V^* = f$ be the dimensionless factor of reservoir utilisation, and $t^* = E_v/N_v$ the (yearly) utilisation factor of the reservoir in hours. Then

$$\frac{N_v}{V^*} = \frac{N_v}{E_v} \cdot \frac{E_v}{V^*} = \frac{f}{t^*}$$

and

$$\beta_v \leqslant \frac{1}{c_v}\left(m \frac{N_v}{V^*} + n \frac{E_v}{V^*}\right)$$

$$\beta_v \leqslant \frac{f}{c_v}\left(\frac{m}{t^*} + n\right)$$

When pumped storage is added to a general-purpose reservoir, then the condition for economical reservoir becomes:

$$\beta_v c_v V^* + \frac{E_P}{\rho_1} \frac{P_{off}}{240} < m N_v + n E_v \qquad \ldots(12)$$

in £ per year, where:

$$\rho_1 = \frac{E_T}{E_P} \text{ and } \frac{E_P}{\rho_1} \frac{P_{off}}{240} \text{ is in £ per year.}$$

The formulae of Musil, as written here, are worked out for a yearly reservoir but can easily be adapted to a shorter period.

The Efficiency of Pumped Storage

Equations (6) and (10) show the overall efficiency ρ_1 of a pumped storage to depend on the product $\eta_P \eta_T$ where

$$\eta_T = \eta'_T \eta''_T \quad \text{and} \quad \eta_P = \eta'_P \eta''_P$$

where η' is the electro-mechanical efficiency of the runner, generator and transformer, and η'' the overall efficiency of the tunnel and pipes. The pipe and tunnel efficiencies are given by:

$$\frac{H - \Delta H}{H}$$

where H is the gross head and

$$\Delta H = \Sigma \frac{v^2 L}{k^2 R^{4/3}} = c v^2$$

the friction losses. (v = velocity in the tunnel or pipe, k the Manning-Strickler friction factor, L the length of the conduit and R its hydraulic radius.) Intake and bend losses are supposed to be included in the factor k.

The amount of power lost by friction and similar losses is:

$$\Delta N = \frac{1{,}000}{75} Q \Delta H \eta' \text{ in h.p.}$$

As $Q = vA$ (A = area of the conduit), the power losses can also be given by

$$\Delta N = \frac{1{,}000}{75} A c v^3 \eta' \text{ in h.p.}$$

$$\text{or } \Delta N = 9{\cdot}81\ A c v^3 \eta' \text{ in kW} \qquad (13)$$

The corresponding energy loss over a period T is

$$\Delta E = 9{\cdot}81\ Ac \int_o^{t_T} v^3 \eta' \, dt \text{ in kWh} \qquad \ldots(14)$$

During the period t_T the load will vary according to a diagram similar to Fig. 5b. The diagrams in Figs. 5a and c are extreme cases. For case c the value of the integral is (η' = constant):

$$\int_o^{t_T} v^3 dt = \int_o^{T} \left(\frac{t}{t_T} v_{max}\right)^3 dt = \frac{v^3{}_{max}}{t_T{}^3} \int_o^{t_T} t^3 dt$$

$$= \frac{v^3{}_{max}}{4} t_T$$

and for any diagrams of the type b it can be shown that

$$\int_o^{t_T} v^3 \, dt = \frac{v^3{}_{max}}{n'} t_T \text{ with } 1 \leqq n' \leqq 4 \qquad \ldots(15)$$

A case of particular interest from the point of view of cost analysis is the comparison of a hydro-power scheme without pumping (maximum pipe velocity v_o and maximum output N_o) and a similar scheme with pumping installed. The addition of the pumps can be made without any change in the power-station capacity, or with an increased capacity. If the power-house capacity is not increased, the maximum velocity v_o remains unchanged and so are the losses for maximum power, but not the losses for energy. In the second case, which will be examined here, both the losses for the estimated power and energy are in-

fluenced by the new conditions. The new maximum velocity is $v_{max} > v_o$ and the maximum output of the pumped-storage scheme is now $N_{max} > N_o$. Assuming the mechanical efficiency to remain unchanged,

$$\frac{\Delta N}{\Delta N_o} = \left(\frac{v}{v_o}\right)^3$$

where ΔN are the power losses due to friction for the two cases considered—that is, with and without pumping. Conservative designs show the value $\Delta N_o/N_o$ to vary between 3 and 8 per cent. If, by introduction of additional pumping, the capacity is increased, then the power losses are increased, too, in the ratio $\left(\frac{v}{v_o}\right)^3$. The loss of power is then given by:

$$\frac{\Delta N}{N_o} = \frac{\Delta N_o}{N_o}\left(\frac{v}{v_o}\right)^3 \qquad ...(16)$$

which represents an additional power loss of roughly

$$\frac{\Delta N}{N_o} - \frac{\Delta N_o}{N_o} \approx \frac{\Delta N_o}{N_o}\left[\left(\frac{v}{v_3}\right)^3 - 1\right] \qquad ...(17)$$

Table V gives some numerical values for formula (16) assuming that the nominal capacity of the power-house in increased from N_o to $N_o + \Delta N^*$ by pumped storage.

TABLE V.—FORMULA $\Delta N/N_o = \Delta N_o\ (v/v_o)^3/N_o$ (16) GIVING THE POWER LOSSES FOR A GIVEN RELATIVE INCREASE $\Delta N^*/N_o$ OF THE INSTALLED CAPACITY IN %

Increase of installed capacity: $\frac{\Delta N^*}{N_o}$ =	$\frac{1}{10}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$
v/v_o =	1·1	1·2	1·25	1·33
$(v/v_o)^3$ =	1·333	1·725	1·96	2·36
For $\Delta N_o/N_o$ = 2%	$\Delta N/N_o$ = 2·667	3·47	3·92	4·72
= 3%	4·0	5·2	5·9	7·1
= 7%	9·35	12·15	13·7	16·5

Some figures may be worked out for particular examples. An existing station with $N_o = 200{,}000$ kW installed is to be enlarged by pumped storage by 1/5 by the addition of one set of $\Delta N^* = 40{,}000$ kW to make a total of 240,000 kW installed capacity. Assuming the losses in the existing station to be 3 per cent. for maximum power, the addition of one set of 40,000 kW brings the friction loss to 5·2 per cent. The real power increase is then to be calculated as follows:

The existing sets are supposed to produce 200,000 kW under a head $H - \Delta H_o$. The new set is supposed to produce 40,000 kW under the same head $H - \Delta H_o$. When all the sets are running they will produce

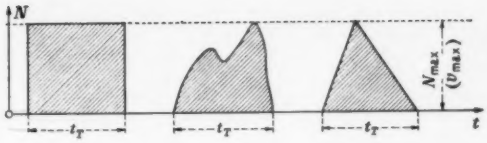
$$240{,}000\ \frac{H - \Delta H}{H - \Delta H_o} = 240{,}000\ \frac{100 - 5{\cdot}2}{100 - 3}$$
$$= 0{\cdot}977 \times 240{,}000 = 234{,}000\ \text{kW}$$

The net power increase is then only 34,000 kW for maximum load when all the sets are running.

If the head loss of the original plant was 7 per cent., the addition of 40,000 kW nominal would cause a real power increase of

$$240{,}000\ \frac{100 - 12{\cdot}15}{100 - 7} = 240{,}000\ \frac{87{\cdot}85}{93}$$
$$= 0{\cdot}944 \times 240{,}000 = 210{,}500\ \text{kW}.$$

The real gain of 10,500 kW against the 40,000 kW additionally installed is a poor result. There is an obvious limit to the possible improvement of the installed capacity of existing stations by adding pump-turbine sets.



a *b* *c*

Fig. 5

From the point of view of the production of energy, the problem might be quite different. If the diagram of energy production is of the type shown in Figs. 5b and c, then the energy losses are to be divided by n', where $1 < n' < 4$. This may considerably reduce the energy losses as compared to the power losses. In addition it may be possible with the new power-to-energy ratio to spread the production of energy over a period t'_T larger than t_T which is also in favour of production of energy.

The problem of conduit losses has been analysed here, considering the set running as a generating set. When the pump is running, the pumping period t_P to be considered will probably be double the time t_T allowed for running the turbine. If the total pumping power installed is, as often is the case, considerably less than the power of the turbine, then the head losses caused by pumping may be relatively small and account for little in the total balance of costs.

(To be continued)

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Fig. 1. Drilling in bedrock, Liuchia Gorge, Yellow River

Water Power Resources of China

By Teng Tsai-shou, B.Sc., Engineer of the Bureau of Hydro-electric Development, Ministry of Power Industry

FAVOURABLE natural conditions make China one of the richest countries in the world as regards water-power potential. According to an estimation compiled in 1955 by the Bureau of Hydro-electric Development, Ministry of Power Industry, the total potential, calculated on average stream-flow, amounts to 544 million kW capacity, a figure which greatly exceeds the many different estimates made in the past.

Precipitation Characteristics

Precipitation in China is mainly in the form of rainfall. With reference to its distribution, the East and Southeast are classified as regions possessing very abundant rainfall, while in the Northwest it is scarce.

The region with the heaviest rainfall is in Taiwan, where the mean annual rainfall reaches about 3,000 mm. Next come the Kwangtung and Kwangsi provinces, and also part of Kiangsi and Fukien provinces. In these regions the annual rainfall ranges from 1,500 to 2,000 mm. The mean annual rainfall for other regions is as follows: the Yangtze River valley, 1,000 mm.; the Hwang Ho (Yellow River) valley, 500 mm.; North China Plain, 600 to 700 mm.; Northeast China, 500 to 1,000 mm.; the plateau of Sikang and Tibet, below 600 mm. The desert area of Northwest China is noted for its dryness; for instance, the Takla Makan Desert of Sinkiang Uighur Autonomous Region has a mean annual rainfall less than 50 mm.

Referring to seasonal variation, it should be mentioned that the greatest part of rainfall in China takes place in the summer months—June, July and August,

Fig. 2. The Sanmen Gorge on the Yellow River; the site of the dam is on the right

or in some cases, July, August and September. According to records, the precipitation within the three-month period may reach 60-80% of the total annual amount. In some regions, the rainfall within a few days may even be as high as 25-50% of the year's precipitation. Such wide seasonal variations lead to stream-flow variations of sometimes a hundred-fold, and even a thousand-fold.

Topographical Features

The topographical features of China, as a whole, can be summarised as being: "high in the West and low in the Southeast." Tibet, the ridge of the world, stands more than 4,000 m. above sea level, whereas the eastern and southeastern parts of China are vast plains, formed by the alluvial deposits of various big rivers. Generally speaking, China is composed of three types of terrain—one third consists of plains, one third plateaus and hills, and one third mountainous regions. Between the western plateaus and the eastern plains, there exist a series of plateaus of lesser heights. As the rivers flow from the high mountainous regions towards the plains or valleys, their channels frequently traverse steep slopes and narrow gorges, which form favourable sites for economic power development.

Recent Estimation of Power Resources

Before 1936, the investigation of water power resources in China was confined only to certain sites near big cities. In the last two decades, however, especially in the last six years, investigation and exploration work has been extended to a much larger area. Compared with the two previous estimates made by the "National Resources Commission" of the Kuomintang government, the new one is much more accurate and complete.

The new estimation was conducted in 1955. It includes 1,598 large and small rivers and covers 70% of the area of the country. The total length of these rivers is 226,600 km., and the total run-off, on average flow, is $2{,}617 \times 10^9$ cu. m. On the basis mentioned above, the theoretical potential water power potential of China is estimated as 544 million kW on average stream-flow; 345 million kW at 50% duration flow; and 94 million kW at 95% duration flow. Particulars of the important river systems are given in Table I.

Method of Estimation

In estimating stream-flow, all available data are collected. The estimates of stream-flow are based on records from hundreds of gauging stations, some of which were established many years ago while others are quite recent. For areas where actual river-discharge records are lacking, rainfall records and other indirect methods are used to estimate the flow.

In order to facilitate the calculation of potential power, rivers are divided into sections. The confluence of main rivers with tributaries, or points where the slope of river bed changes, are chosen as sectional points for calculation. The basic formula used for this purpose is:—

$$N = 9{\cdot}8\frac{Q_1 + Q_2 H}{2} \quad \ldots\ldots\ldots\ldots (1)$$

where N = potential water power in kW for the section considered, Q_1, Q_2 = discharge in cu. m. per sec. at both ends of same section, and H = gross head for same section in metres.

Near the river sources, the profile generally takes the shape of a hyperbola. In this case, equation (1) gives higher value of power than it should be, therefore, a coefficient of 0·5 is used to modify the result obtained:—

$$N = 4{\cdot}9\frac{Q_1 + Q_2 H}{2} \quad \ldots\ldots\ldots\ldots (2)$$

For the section at the river's origin where $Q_1 = 0$;

$$N = 2{\cdot}45\, Q_2\, H \quad \ldots\ldots\ldots\ldots (3)$$

As regards international rivers, the water-power resources are estimated as follows: for rivers flowing into a neighbouring country, the potential power is

TABLE I. STATISTICS OF WATER POWER RESOURCES

No.	Water System	Potential Power (10^6 kW) at Q_{95}	at Q_{50}	at Q_{ave}	% according to col. (5)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Grand Total	94	345	544	100·0	
1	Yangtze River System	42·2	144·9	217·0	39·9	
2	Rivers in Tibet ...	16·5	70·4	117·2	21·5	
3	Southwest International River Systems	12·3	53·6	90·6	16·7	
4	Hwang Ho System ...	8·5	24·0	32·7	6·0	
5	Chu Kiang System ...	4·6	16·5	28·5	5·2	
6	River Systems along Southeast Coast ...	3·8	12·4	20·4	3·8	Including Taiwan and Hainan Is.
7	Northeast River Systems	1·3	9·7	18·9	3·5	Including Lwan Ho
8	Northwest Inland River Systems ...	4·6	12·7	17·5	3·2	
9	Hai Ho System ...	0·2	0·8	1·2	0·2	

calculated up to the national boundary; for rivers forming the international boundaries, only half of the potential is taken into account.

As further exploration is now being extended to every part of the country, the figures given in this article are subject to revision.

The Big River Systems

The Yangtze. This river is the largest river in China and has a drainage area of 1·94 million sq. km., with an average discharge of 32,500 cu. m. per sec. The overall drop of the river is about 5,000 m. Its major tributaries are the Min Kiang, Kialing Kiang, Yuan, Tze, Han rivers, all of which have a large volume of flow and a steep gradient, with consequent high power potentials.

With technical assistance from USSR, a plan is being worked out for the multiple-purpose development of the Yangtze river. The main object of this scheme is for flood-control, hydro-electric power, irrigation and navigation. Up to the present, a number of possible important sites for the construction of barrages have been preliminarily investigated. One of these, in the Yangtze Gorge near Ichang, in Hupeh Province, possesses the possibility of developing 15 to 20 million kW, while another, in the vicinity of Chungking in Szechwan Province could sustain a capacity of 6 million kW, and third, at Ipin in Szechwan Province, also has 6 million kW potential. On the tributaries of Yangtze, Wuchiangchi on the Yuan river in Hunan Province is a site for 2 million kW, while on the Han river, Tankiangkow in Hupeh Province is also a promising site. Careful study is now being made to decide which of these sites will be chosen to give the most favourable economic results.

Hwang Ho (the Yellow river). Unified planning of the multiple-purpose development of Hwang Ho was completed in 1954. This scheme will not only help to solve the problems of flood control and irrigation and navigation, but will also lead to a complete development of the power resources of the river. According to the plan, there will be 46 successive stages from the Lungyang Gorge in Chinghai Province to the sea, with a total installation of 23 million kW, and a total energy production of 110×10^9 kWh per annum. The Sanmen Gorge project, with a capacity of one million kW, will be developed first. Constructional work will begin in 1957. The next stage to be tackled will be the Liuchia Gorge project, near Lanchow, also of one million kW capacity.

Huai river. The Huai river system is situated between the Yangtze and the Hwang Ho. The greatest part of the valley consists of flat country with gentle river slopes. As a result of abundant rainfall in this area, floods are very frequent. Within the last few years, a series of dams has been built for flood control. The Futzeling and Meishan reservoir projects, completed recently, have already acquired good results in holding water during the rainy season. In the meantime, small hydro-electric power units are being installed.

Chu Kiang (the Pearl river). The Chu Kiang valley, situated in South China, has abundant rainfall and a moderate climate. The seasonal variation of the stream-flow is not remarkable. As the coal resources in South China are not as rich as in the North, water power development on the Chu Kiang has special significance.

International rivers. The international rivers in the Southwestern part of China are the Nu Kiang (Salween), the Mekong river, the Irrawaddy, the Red river, and so on, all originating in the transversal mountains in Southwestern China. They generally run southward into Burma, Viet Nam and Laos. These rivers are characterised by steep slopes and abundant flow and consequently offer great promise of water-power development.

The Brahmaputra. This river, which has its source in Tibet, flows from west to east across the Tibet plateau. In the vicinity of the 95° meridian it turns abruptly towards the southwest, flowing into the plain of India. A very large drop exists in the section of the turn. According to recent surveys, there is a total fall of over 2,400 m. in a distance of less than 50 km. straight across the bend. With a discharge of about 2,000 cu. m. per sec., the potential water power is estimated to be about 50 million kW, which makes it the one most outstanding place in the world for hydro-electric development.

Rivers along the Southeast Coast. The provinces along the southeast coast are mostly made up of hilly terrain. Rainfall there is abundant, but the rivers are comparatively short, and the Min Kiang offers the best prospects for water-power development. The estimated amount of power is about 3 million kW. In Chekiang Province, the Sinan Kiang project will soon be constructed to meet the growing demands for electrical power in Shanghai and its vicinity.

Rivers in Northeast China. Rivers in the northeast may geographically be classified into two systems. One of these contains the rivers flowing northward into the Amur river, the Sungari being the most significant. The other system, with the rivers flowing into the Pohai, consists of the Liao Ho and the Yalu Kiang. China and the USSR are at present making a joint investigation into the development of the Amur river.

Inland Rivers in Northwestern China. Because investigating and surveying work has just begun, there is insufficient information to draw conclusions about the water-power resources of the inland rivers of the northwest. They are however fed partly by snowfields, so that the stream-flow is comparatively stable. In this area, the rivers will be developed for irrigation as well as for power.

Recent Hydro-electric Development in China. The People's Republic of China has been paying particular attention to the development of hydro-electric power and water conservancy projects, with a view to speeding up national industrialisation, which will need a large amount of electrical energy, as well as the elimination of serious floods.

During the last three years efforts have been made to rehabilitate the hydro-electric plants damaged in the war. At the same time, investigational work was resumed and surveys of some major rivers of the country, including the Hwang Ho, have been made. Since 1953, the first year of the First Five-year Plan, China entered upon the period of planned reconstruction. The hydro-electric plants which have been put into commission in the last six years are: the Kwanting plant near Peking, the Kutien plant in Fukien Pro-

(Continued on page 64)

Power Development in Sweden

A brief review by Olle G. Gimstedt, Managing Director
of the Swedish Water Power Association

IN 1955 the total power consumption in Sweden, including transmission losses, was 25,000 million kWh. Estimates of expected consumption during the next ten years show an average increase of 1,700 million kWh annually over the period 1956-61 and 2,250 million annually between 1961 and 1965. The principal reasons behind this are illustrated in Fig. 1, where simplified trend lines of industrial production, manhours, power consumption in industry and total electricity generation are shown with 1935 as base year. The basic trend line is that of industrial production, where an average annual increase of about 3 per cent. is anticipated. Put together with the trend of manhours in industry, which will level out and even decrease, due to higher efficiency and subsequent demand for a shorter working week, this will necessitate higher mechanisation and an increase in industrial power consumption of 4—5 per cent. annually. Finally, domestic consumption will take an ever-growing share of the total consumption, here the annual increase at present surpasses 10 per cent. All this will result in the graph depicting required electricity production.

To meet this demand the power supply enterprises have planned their development programmes. (Here must be mentioned the fact that practically all power plants are interconnected by transmission lines, making possible an efficient co-operation between the different power undertakings). Considering the cost of hydro power produced in plants now under construction and planned, and transmitted to load centre, which amounts to 2·5-3 oere per kWh, as well as the statistical availability of water for power production, and the cost of thermal power, produced from coal at a price of 125 kr per ton or oil at 115 kr per ton, it can be shown that the best overall economy will be attained when the average generating capacity of water power exceeds the primary load by 10 per cent. The power-supply enterprises therefore plan the development of their water-power resources accordingly, as shown in Fig. 2. Here also are separately indicated the development programme of the government-owned enterprise, the State Power Board, and the aggregate production programme of private and municipal power companies. At present the latter represents 58 per cent. of total production.

The activity in hydro-power development in recent years and the near future is illustrated in Fig. 3. From this can be seen that at present there are under construction power plants corresponding to a generating capacity of 1·8 million kW, and that this figure will increase during the years to come.

The principal trends in design of hydro-power projects have been: larger-capacity generating units, underground plants with rather long, unlined tailrace tunnels, and earth and rockfill dams. The largest-capacity turbines are going to be installed at the Stornorrfors project on the Ume river, driving three generators (in the future four) with ratings of 132,000 kW each. The cross section of the 4,000 m. tailrace tunnel is 390 sq. m. Another project on the same river, the Harrsele plant, has a tunnel with a length of 3,400 m. and a cross section of 250 sq. m. In respect of dams a project under construction on the Dalaelven should be mentioned, the Traengslet, where a rockfill dam

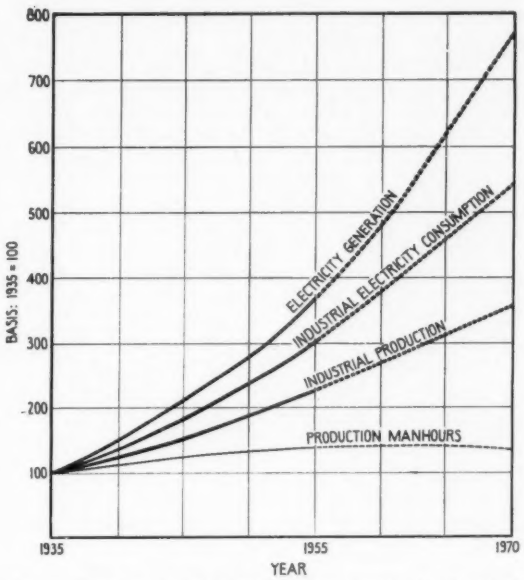


Fig. 1. Past and estimated future trends in Swedish electricity supply and industrial production

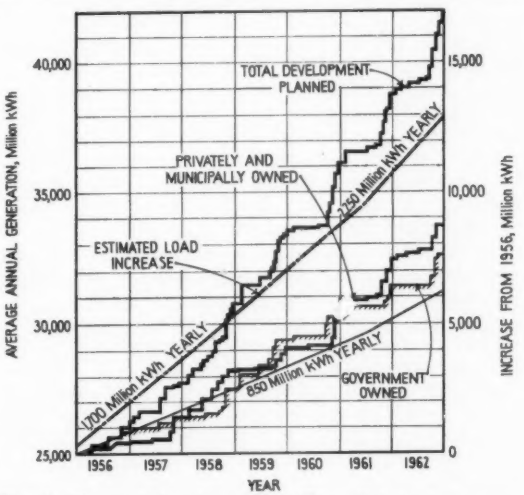


Fig. 2. Planned development of Swedish hydro-power resources

with a volume of 7·5 millions cu. m. is being built. Construction is to be started next year on a still larger dam at Messaure on the Lule river, which will have a volume of 12 million cu. m.

Accompanying the development of hydro power is the construction of new thermal plants. Serving mainly as peak-load plants, their aggregate installed capacity has to follow the hydro-electric plants in at least the same ratio as at present, or above 20 per cent. The largest steam condensing plant now under construction is Stenungsund, on the west coast. It will be located entirely underground.

In the future Sweden has to cover its power requirements with increasing supplies of thermal power, and therefore also the planning of atomic power developments is well under way. Plans for a 100,000 kW atomic plant are under elaboration; this project is scheduled to start operation in 1963.

The picture presented here of the planned power developments in Sweden may look a bit too bright, but we hope that our programmes can be realised. It would be unwise to deny, however, that several adverse conditions exist that may delay progress. The most important of these are financial ones. The development of hydro power—not to speak of atomic power—implies rather heavy capital requirements. At present necessary annual investments for power plants, transmission and distribution systems amount to about 900 million crowns representing about 23 per cent. of total investment in industry or 7 per cent. of all investments, and the question is if the necessary credits can be obtained.

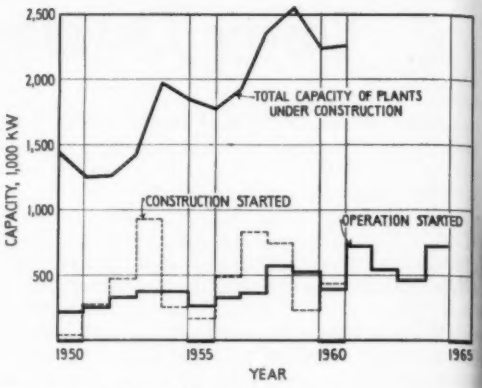


Fig. 3. Swedish hydro plants under construction

Another retarding influence is the growing resistance against power projects with regard to the alleged spoiling of natural scenery, notwithstanding the fact that in connection with all present planning of hydro-electric projects the local interests are consulted.

From page 62

vince, the New Shihlungpa plant near Kunming in Yunnan Province, the Ulapei plant near Urumchi of Sinkiang. The rehabilitation and installation of new units in the Fengman plant are nearly completed, and the hydro-electric plant near Lhasa in Tibet will be completed this year.

The projects under construction are the Hwangtankow plant in Western Chekiang Province, the Shangyiu plant in Southern Kiangsi Province, and the Ili plant in Northern Yunnan Province, etc. Preparations are now being made for the construction of the Sanmen Gorge project on the Hwang Ho.

The more prominent projects under consideration include the Liuchia Gorge scheme on the Hwang Ho, the Sinankiang scheme near Shanghai, the Minkiang scheme near Chengtu (in Szechwan Province), the Nanpankiang scheme) in South Yunnan Province) and the Liuchiho scheme near Canton, and a few schemes on the larger tributaries of the Yangtze river. The construction of some of these schemes is expected to start within one or two years and the others in the period of the Second Five-year Plan.

In order to give a general idea of the scale and speed, as well as the complexity of water-power development in China, both at present and in the near future, it is appropriate to mention the following features: (1) the plans include projects with capacities of more than one million kW and with concrete volumes of 2 to 3 million cu. m.; (2) underground power-houses, or power-houses in the dams; (3) turbo-generator units of 80,000 to 150,000 kW capacity; (4) plants with heads of up to 600 to 700 m. for a single stage; (5) relatively high rates of construction—for instance, only 2½ years from commencement to completion for a 50,000 kW plant including the construction of a 50 m. high dam, a water channel, power-house, and the installation of the turbines and generating equipment.

At present, the hydro-electric capacity has not yet reached 20% of the total installed generating capacity in the country, but it is expected that the ratio will be raised to 28% in 1962 and 40% in 1967.

From the above brief survey it can be seen that the New China has already made a good start in developing the water-power resources of the country. As the work of industrialisation of the country goes on, the development of water power will be carried on at a higher and higher tempo. These resources, so long neglected, will be used to improve the welfare of her 600 million people.

Compressed Air Firms to Merge

A merger is being arranged between two important names in the compressed air industry. They are Holman Bros. Limited, of Camborne, a private company founded in 1801, and Broom & Wade Limited, of High Wycombe, which has been a public company since 1935. Holman Bros. also control the Climax Rock Drill and Engineering Works Limited.

The arrangement will strengthen the export business of the two companies which already amounts to over 50 per cent of their joint output and it will enable the Holman factories in South Africa and Australia to assist in maintaining the equipment of both companies overseas.

Both companies have had a very successful record for many years past and at present are working full time and with full order books. Both firms emphasise that the degree of overlap in their products is small and that when similar they are being sold in different markets.

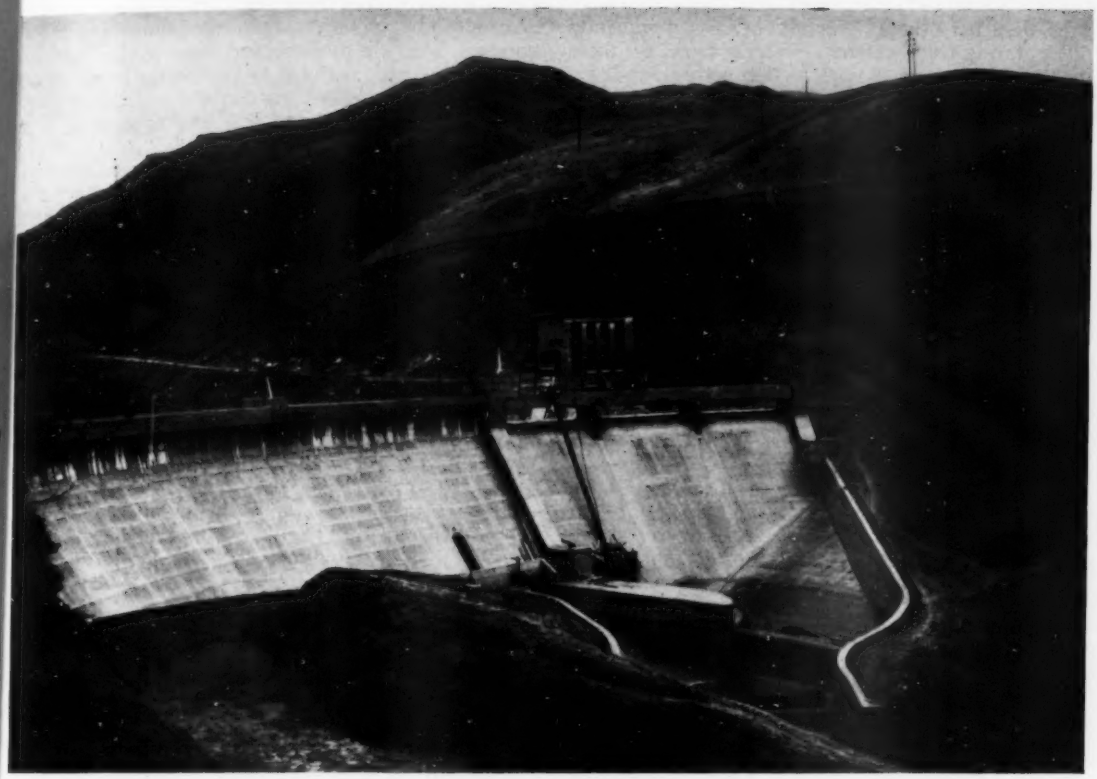


Fig. 15. Spillway section of the Lower Dam

The Glen Shira Scheme

This project, promoted by the North of Scotland Hydro-Electric Board, is designed for peak-load purposes and will be capable of generating 80 million kWh per annum at a load factor of 20 per cent.

PART TWO

THE low-pressure offtake tunnel connecting the lower dam with the top of the pressure shaft is 21,050 ft. long and has a finished diameter of 10 ft. A circular section was decided upon in view of the soft nature of the rock (schist and phyllite) and it is lined with concrete having a minimum thickness of 8 in. In weak sections of ground, comprising 5½ per cent. of the total, steel supporting arches were used. At two points where streams are crossed steel pipes were introduced.

Drilling rates through the soft schists were very good and the overbreak moderate. Once exposed, however, the rock surface weathered rapidly and a good deal of trimming was necessary before the lining could be inserted. The concrete was placed by a pneumatic machine of 1 cu. yard capacity which worked in conjunction with a travelling steel shutter, designed by Parry, 200 ft. long. For the two main lengths of tunnel the concrete was mixed at a central weigh-batching plant at the Brannie-Burn crossing and transported in remixing cars of 3 cu. yards capacity. An average advance of 550 ft. a week was achieved, including a record of 1,020 ft.

The length immediately north of the Allt-an-t'Sithein valley was carried out by cut-and-cover methods and is heavily reinforced. Here the hydrostatic pressure is of the order of 25 lb. per sq. in. and the concrete ring is 9 in. thick and is reinforced to the extent of 2·55 cwt. of steel per cu. yard. It was poured in 30 ft. panels between which 4 ft. 6 in. contraction

gaps were left, these intervals being subsequently filled, during cold weather, after a lapse of three months. This form of construction not only reduced the cost but also effected a saving in steel at a time when it was in short supply.

Pressure Shaft and Surge Tank

Several considerations led to the adoption of an underground power station and pressure shaft. A detailed analysis showed that the price differential between a surface and underground layout was negligible, and the latter arrangement had the advantage of saving 350 tons of steel; furthermore, it obviated an exposed pipeline running down the hillside—always rather unsightly and involving maintenance charges.

The location of the upper end of the surge shaft was determined by the site conditions, and the arrangement adopted, with the pressure and surge shafts inclined on the same axis, not only facilitated the handling of the steel-lining sections but enabled a major stream diversion to be introduced into the surge shaft in a more convenient way.

Upstream of the power house the pressure shaft was driven at full section at a rising gradient of 1:100 for a distance of 600 ft., being then curved vertically and extended upwards at a gradient of 1¼ horizontal to 1 vertical for a distance of 1,450 ft. In driving this steep portion of the tunnel the rock spoil was allowed to accumulate on the slope until the horizontal axis of the cross section was reached when it was then removed by a scraper loader situated at the bottom. This machine was operated at intervals, the aim being

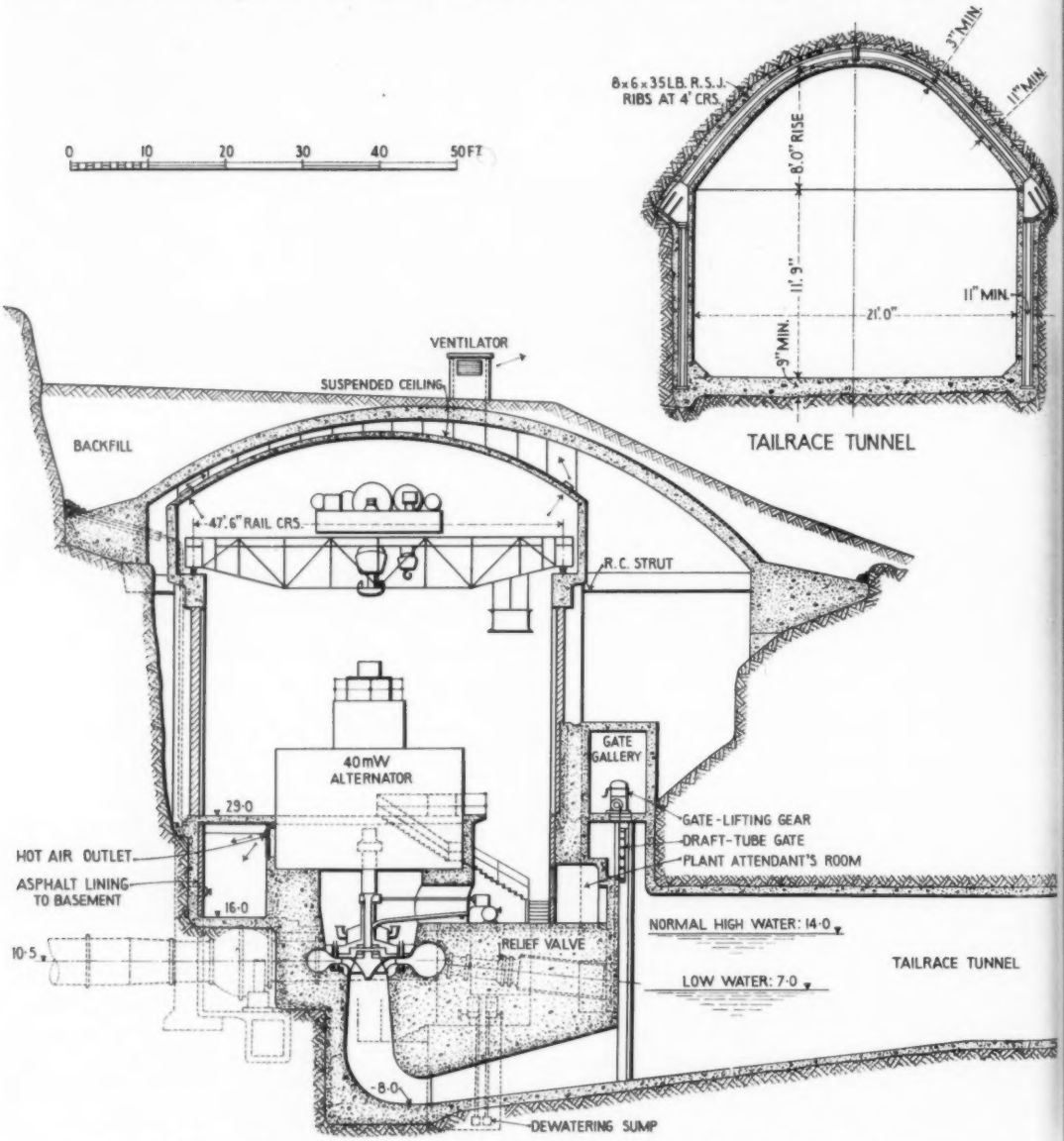


Fig. 16. Details of underground generating station, Clachan, and cross section of tailrace tunnel

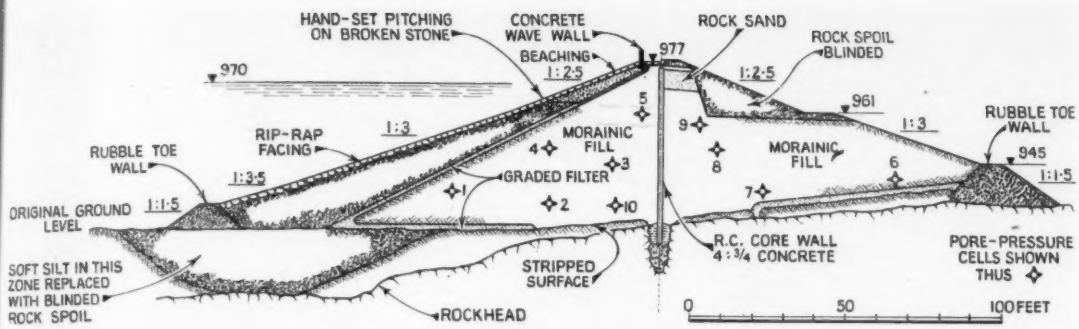


Fig. 17. Section of earth embankment, Lower Dam

to keep the floor of the tunnel covered with an appreciable depth of soil so that its downward drift towards the loader could be controlled to some extent. It should be explained that the angle at which the tunnel is graded, 39° to the horizontal, is slightly in excess of the natural angle of repose of the spoil and was purposely chosen to facilitate its removal. The strata encountered—quartz-schist with occasional igneous intrusions—is much harder than the mica-schist and phyllite traversed by the main tunnel; there was, however, one favourable circumstance in that the average angle of dip, 40°, caused the axis of the steep portion of the tunnel to be virtually normal to the bedding planes. In consequence, no temporary support was needed. Driving rates of up to 40 ft. per week were achieved in the lower reaches but this rate tended to fall off during the excavation of the upper lengths where the diameter was greater and as travelling distances increased. To accommodate the equipment small chambers were excavated in the side of the tunnel at intervals of 250 ft. To protect them from damage, the service pipes were mounted above the axis line of the tunnel, clear of the sliding debris.

The shaft is provided with a steel lining throughout, this being backed by concrete which was subsequently pressure grouted. Grouting pressures ranged from 25 lb. per sq. in. at the top to a maximum of 200 lb. per sq. in. at the lower end before the rock cover thin-

Fig. 18. Control room, entrance portal to powerhouse, and tailrace, Clachan

ned out. At the top the thickness of the lining is $\frac{7}{16}$ in., ranging progressively as the rock cover thins out to a maximum thickness of $1\frac{9}{16}$ in. at the generating station, where the full hydrostatic pressure, including water-hammer effects, has to be met. Flange joints with a double sealing ring were used for pipes Nos. 1 to 53, while welded joints having an outer cover strap—to facilitate assembly—were used for Nos. 54 to 87. In this way site-welded joints were restricted to horizons in which the internal pressure did not exceed 275 lb. per sq. in. The internal diameter of the steel lining is 8 ft. at the top and tapers down to 6 ft. at the bottom.

A disconcerting incident occurred during the grouting; while strake No. 65 was being injected there was a loud report at strake No. 67, where a large bulge appeared. At this moment the predetermined grouting pressure at strake No. 65 had inadvertently been exceeded. Investigation showed that upstream of the flanged section of the lining, certain areas gave out a hollow-sounding ring when tapped. On drilling holes through the lining at these points it was found that there were clearances which ranged from 10^{-3} in. to a maximum of 5×10^{-3} in. and it was concluded that these spaces were due chiefly to the steel lining contracting on cooling while the concrete was still immature and partly to the shrinkage of the concrete itself. The absence of hollow-sounding areas in the flanged section of the lining was attributed to the flanges and securing bolts forming an effective anchor with the surrounding concrete.

On cutting out the damaged portion it was found that the concrete backing was fouling the replacement plate in places, the inference being that the pipe must have been slightly flattened in the first place and yielded when the excess grouting pressure was momentarily reached. After the repair was effected gauge pressures of up to 100 lb. per sq. in. were recorded, which correspond with the static head to the surface. This results from the fissured intrusion of epidiorite which is traversed by the pipeline at this

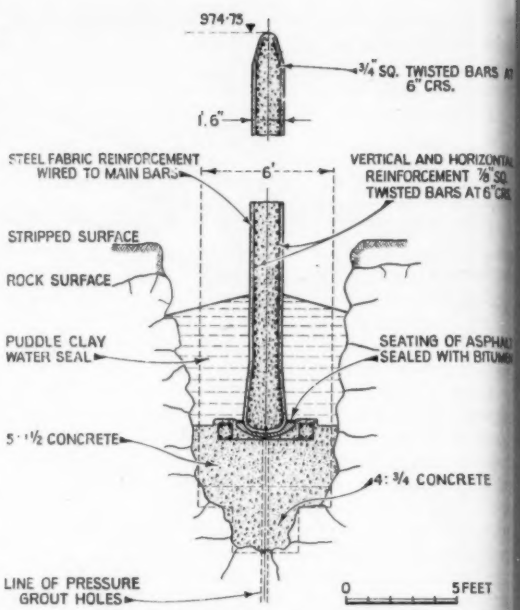


Fig. 20. Detail of reinforced-concrete core wall (see Fig. 17)

point and permits ground water to percolate to a relatively impervious zone of quartz schist that acts as a barrier and so causes a build up of pressure.

Before applying the protective coatings to the interior of the lining, the surfaces were flame cleaned to remove rust and mill scale. The first priming coat was applied while the metal was in a warm condition, in order to overcome any difficulty of adhesion in the humid conditions which prevailed; four coats were given altogether.

The surge shaft is concrete lined and has a finished diameter of 20 ft. At the top, on the surface, there is a pond which serves the double purpose of accommo-

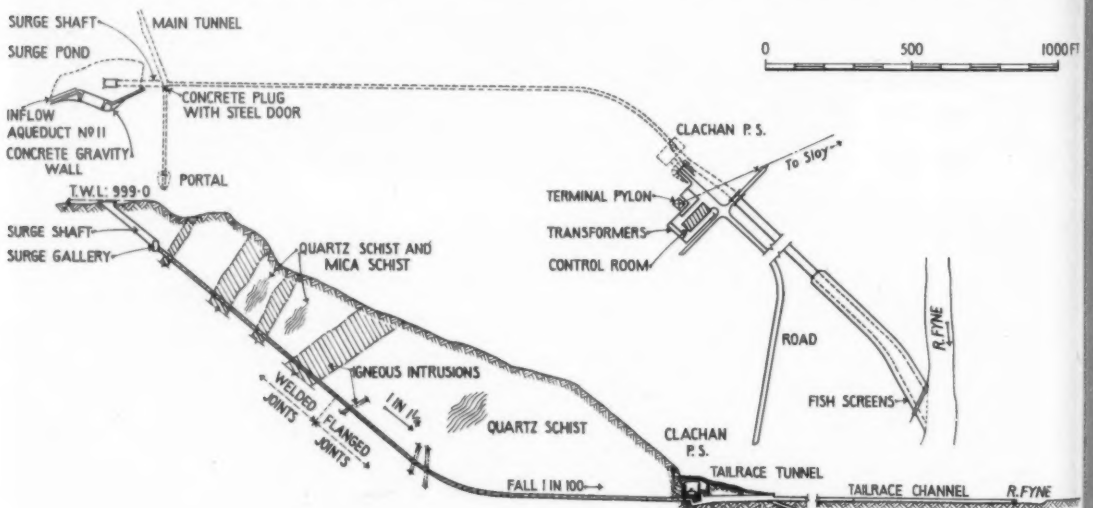


Fig. 19. Sectional plan and elevation to show disposition of surge shaft, pressure shaft and power station

Fig. 21. Clachan generating station; view from the tailrace showing draft-tube shutter and pressure shaft

dating any overflow and of receiving water from a surface aqueduct. At the point where the low-pressure tunnel interconnects with the surge and pressure shafts a lower chamber has been excavated to supply water for downward surges when the water level in the reservoir is low.

Generating Station

The underground power station at Clachan is equipped with a single 56,000 h.p., 428 r.p.m. Francis turbine vertically coupled to a 40 MW, 11,000 V, 0·8 p.f. generator. This set operates under a gross head of 960 ft., the generator being the largest-capacity water-driven unit in the country. The weight of the turbine equipment is 162 tons and that of the generator 303 tons, making a total of 465 tons. The maximum weight to be handled during assembly and dismantling is 140 tons and a crane of 150 tons lifting capacity has been provided. At full load the turbine passes 630 cusecs.

Excavation work above the main floor level was accomplished by opencast methods, a sinking subsequently being made and extended to intersect the pilot tunnel driven to gain access to the pressure shaft.

The basement walls were poured directly against the rock, and to exclude dampness the inner faces are sealed with asphalting which is kept in position by a brickwork lining. To provide a rigid gantry for the 150 ton overhead travelling crane, the reinforced girders and columns were anchored both longitudinally and transversely into recesses cut into the solid rock. Apart from the gain in rigidity this form of construction led to an economy in cost. The arched reinforced-concrete roof is sprung from skewbacks cut into the rock above crane-gantry level, so that no additional load whatever is imposed on the crane columns. Underneath the main roof a reinforced plaster ceiling has been suspended in such a way as to leave a cavity through which air can be circulated and subsequently vented through louvred outlets at the surface. The walls between the reinforced-concrete framework are filled in with brickwork and finished with vermiculite plaster to minimise condensation effects.

It will be seen from the general plan of this scheme (Fig. 2) that the tailrace does not follow the obvious course to Loch Fyne. The deviation was made on expert advice with the object of stimulating migratory fish to enter the river to breed, rather than to distract them by a second flow of fresh water directly into the Loch. This less-direct route necessitated the construction of fairly extensive tailrace works, involving a concrete-lined tunnel, 21 ft. wide and 100 ft. long, driven into the rock and followed successively by a cut-and-cover section 150 ft. long, a concrete-lined channel 27 ft. wide and 930 ft. long, and finally an outfall portion, 600 ft. long, of trapezoidal section and having a concrete invert and the side slopes lined with random rubble pitching. A fish screen of 2 in. square mesh is provided where the tailrace terminates on the west bank of the river.

The control room and administrative offices for

both the Clachan and Sron Mor stations are situated in a building outside the entrance portal of the Clachan plant and flanking the outdoor switching station. The main 40 MVA transformer is also situated near this portal and feeds the 132 kV transmission lines to the Inveruglas switching station, 10 miles distant, near the Loch Sloy plant.

Diversion Aqueducts

The high head and the unusually high incidence of rain in the Glen Shira region combine to make any extension of the run-off area extremely attractive. Extensive collecting works have consequently been undertaken as part of the scheme. These comprise free-flow tunnels, concrete-lined aqueducts and piped aqueducts. As a rule these have been designed to carry $4\frac{1}{2}$ to 5 times the average flow, but in certain short sections which could be cheaply constructed the carrying capacity has been designed to accommodate 10 times the average.

Spun concrete pipes are considered to be the most economic form of construction for waterways up to an equivalent diameter of 42 in., and flexible joints have been used with marked advantage. These joints are not only easily connected in adverse weather conditions but also permit angular deviations of up to 2° to be negotiated, thus reducing the depth of excavation on sections where the hillside is ridged, as is not uncommon. For larger works a concrete-lined canal of trapezoidal cross section has proved the most economical, the width being twice the depth and the walls battered 1 horizontal to 2 vertical. In view of the difficulties that can be caused by snow and frost these canals are covered over with factory-made prestressed concrete slabs. Considerable quantities of debris are liable to be carried by even small burns in times of flood, particularly in regions where the rock is covered with an overburden of moraine. It was thus decided that the usual form of intake, consisting of a bar screen mounted on the upstream face of the weir, or on the side approach to the intake, would not be adequate and that a self-cleaning type of screen, or alternatively, an intake without any screens at all, should be adopted. A typical intake for small streams, incorporating a self-cleaning screen mounted at an angle on the downstream side of the spillway, is shown in Fig. 23. Normally the screen accepts the full flow over the lower inlet crest but in times of spate part of the flow is bypassed over the stepped flood crest. A number of these intakes have now been in service for some time and have proved very satisfactory, requiring little or no attention from the maintenance staff.

For larger streams the screen has been eliminated altogether and a baffle wall substituted to divert the debris. In this design excess water flowing over the intake is diverted by a steel nose piece which splits the nappe. Floating material is kept away from the inlet well by means of a trash baffle, which prevents the intake water from being drawn from the surface. Details of this type of intake are shown in Fig. 24. Each design was perfected in the light of information gained by hydraulic model studies.* Each intake has been generously proportioned with the object of assuring that it would be capable of accepting more water than the design yield, and relief spillways, situated downstream, have been provided to reject any surplus which would surcharge the system. In this way advantage can be taken of a heavy incidence of rainfall over any part of an aqueduct, as it has been proved that the precipitation is by no means uniform throughout the whole length of an aqueduct, even on the small catchments. To this end the Brannie Burn intake,

* "Stream Intakes," by W. Sommerville; Students' Paper, Institution of Civil Engineers.

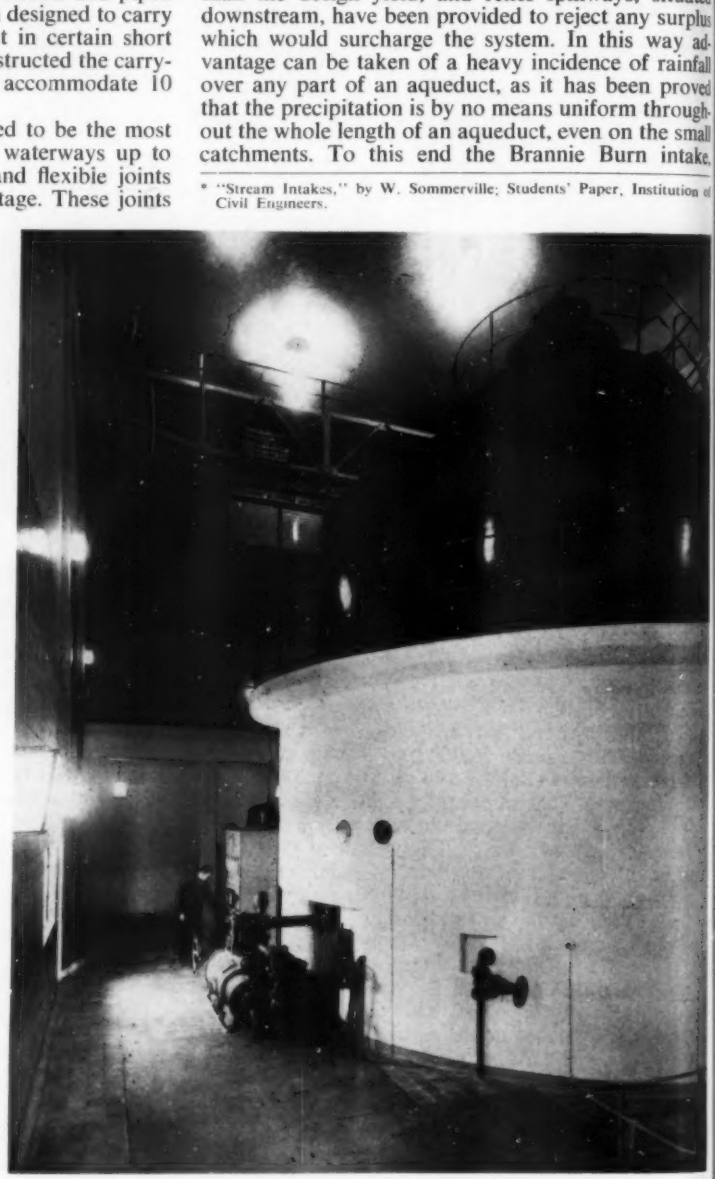


Fig. 22. Interior view Clachan powerhouse

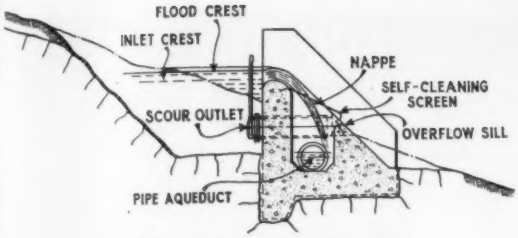
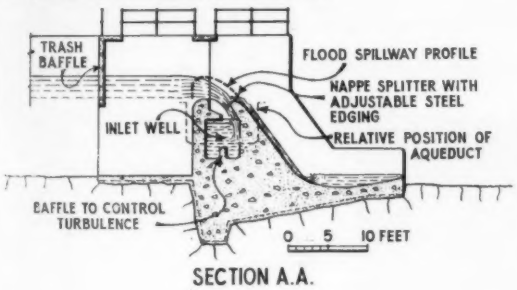


Fig. 23. Intake for small stream

which controls about one fifth of the total run-off area, has been designed to deal with 189 cusecs, or nearly one third of the full-load flow. Similarly, the Kilbraan and Clachan diversions, both of which are fed directly into the surge shaft, have been designed to deal with a maximum flow of 136 cusecs, although they control only 2·44 sq. miles of run-off together.

To deal with the problem of entrained air, experiments were conducted to study the behaviour of water flowing down a steeply inclined shaft so proportioned that at least one third of the cross-sectional area was available for air release. Also, the release of entrained air by the provision of an expansion chamber associated with the surge chamber was studied. The results of both these studies were incorporated in the scheme. For feeding the Brannie diversions into the tunnel a steel pipeline, 48 in. diameter, was laid at an average gradient of 1 : 6·4; thus at all times there is ample space above the flow for air release, while an enlargement of the tunnel at the foot of the surge shaft serves to slow down the rate of flow sufficiently for any entrained air to separate out and find its way up the inclined surge shaft. Both these works have proved to be perfectly satisfactory in service.



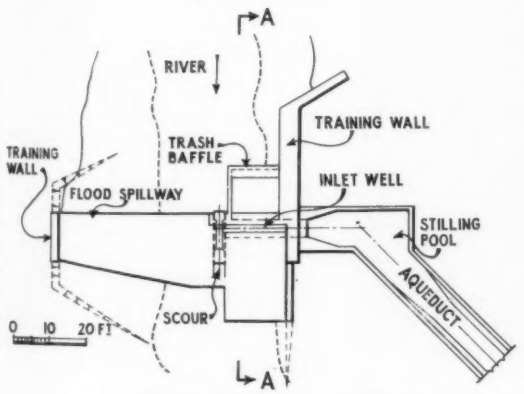


Fig. 24. Intake for major stream

Roads and Constructional Plant

Some 15 miles of access roads had to be constructed, mostly over rough ground overlain with moraine, which, although generally shallow, was apt to become unstable on the steep glaciated side of the valley when disturbed by the necessary excavation work. Progress was consequently rather slow and a period of 18 month elapsed before a start could be made on some parts of the works.

In all some 500,000 tons of aggregate were required for the scheme and to supply this a quarry was opened up, about half a mile from the site of the main dam, where there is an outcrop of epidiorite. This material was handled by a quarry plant which was formerly used for the Loch Sloy scheme, being modified to some extent to meet the different conditions. It is capable of a daily production of 1,000 to 1,200 tons of sized and washed aggregates, and as the nearest source of natural sand is some 45 miles distant, the plant was used to provide about 70 per cent. of the fines needed, in the form of rock crushed to sand size.

To accommodate the personnel employed on the scheme, a disused military camp, constructed during the last war, was taken over and re-equipped for a peak labour force of 800 workmen.

Acknowledgments

We have pleasure in recording our thanks to the North of Scotland Hydro-Electric Board for their courtesy in allowing us to inspect this interesting scheme and to publish our article. We also acknowledge our indebtedness to Messrs. Babtie, Shaw & Morton, M.M.I.C.E., consulting engineers for the civil-engineering works associated with the project, and especially to Mr. John Paton, M.I.C.E., one of the partners, who very kindly allowed up to draw heavliy on the data published in a paper presented to The Institution of Civil Engineers.*

The consultants for the mechanical and electrical sections of the work were Messrs. Merz and McLellan, and the whole scheme as carried out conforms very closely to the original conception of the late James Williamson, M.I.C.E., a member of the Board's panel of technical advisers.

Main contractors. The civil-engineering works were subdivided into three main contracts and a tender for the whole of the work submitted by A. M. Carmichael Ltd., of Edinburgh, was accepted. The main contract for the generating plant at both Sron Mor and Clachan was awarded to The English Electric Co. Ltd., who arranged for the pumping plant at Sron Mor to be manufactured by The Harland Engineering Co. Ltd., of Alloa. Other important electrical equipment was supplied by A. Reyrolle & Co. Ltd., The British Electric Transformer Company, The Yorkshire Electric Transformer Company, and Bruce Peebles & Co. Ltd. The larger steel pipework and tunnel linings were entrusted to P. & W. MacLellan Ltd., and Mechans Ltd., while the smaller pipework was supplied by Stewarts and Lloyds Limited. The main control gates were manufactured by Glenfield & Kennedy Limited. The quarry plant was installed and operated by Keir & Cawder Limited, of Glasgow, and the cableways for the main dam were by John M. Henderson & Co. Ltd., of Aberdeen.

* "Glen Shira Hydro-Electric Project." Paper presented to The Institution of Civil Engineers. April, 1956.

Driving the Eucumbene-Tumut Tunnel

A contributor gives a brief account of the methods employed in executing this stage of the Snowy Mountains scheme

THE Snowy Mountains scheme, in the Australian Alps, comprises two separate but related developments—the Snowy-Murray and the Snowy-Tumut.* In the Snowy-Tumut development the Eucumbene River, which flows in the Adaminaby Valley, will be diverted to the Tumut, a tributary of the Murrumbidgee. The Eucumbene is now being dammed to form the Adaminaby reservoir, which will be the largest in Australia. The water therefrom will flow through a tunnel 14 miles in length to the Tumut River, where a high concrete dam, now in course of construction, will retain this additional water and pass it through another generating station, T1, the first of a series along the Tumut River.

Work was first commenced on the upper reaches of the Snowy River, where the Guthega project was first completed.† Attention was then turned to the diversion of the Eucumbene into the Tumut, the driving of the 14 mile diversion tunnel being the subject of this article.

Successful tenderers for the work were a number of United States contracting firms acting jointly. They were Kaiser, Walsh, Perini, Raymond sponsored by Kaiser Engineers. Over 15 miles of tunnel are now being excavated and they will be lined with concrete to give a finished inside diameter of 21 ft. As well as the main tunnel, other works to be constructed include a junction shaft which meets the tunnel 9·8 miles along its length and gives the opportunity to work from two faces. A 14 ft. horseshoe-section unlined drainage tunnel has also to be driven to allow emptying of the main tunnel without drawing down the pond at the end of the downstream pressure tunnel.

Drilling of the tunnels is now well under way. From the Eucumbene portal a considerable distance has now been covered and the junction shaft has been sunk, allowing tunnelling to proceed from three faces for more rapid progress. Speed is absolutely essential in this work as the main tunnel must be driven and lined by the beginning of 1960.

Considerable variation in the type of rock has been met with even in this early stage of the work. Varying as it has between a soft broken quartzite and a hard granite, the roof has required support by steel sections and timber lagging in some lengths whereas in others the roof has stood on its own. Fortunately, as far as driving has proceeded, water has not caused a great deal of trouble although in one or two cases grouting has been employed.

A drilling jumbo has been specially designed for the work by the contractors and has been constructed in their workshops on the site. It runs on rails at 14 ft. centres and has three banks of four Gardner-Denver Model CF 93 drifters mounted on hydraulic booms. One bank is situated at floor level and the other two are on two platforms above. Drill steel consists of 1¼ in. diameter hollow round stock manufactured by the Australian Commonwealth Steel Pty. Ltd., and these are tipped with Ingersoll-Rand cross-bits with tungsten-carbide inserts.

In good working conditions it was found possible to drill approximately sixty holes to a depth of 12 ft. The explosive used was a gelignite of 40 per cent. strength and gasless detonators were used with varying half-second delays.

The blasted material is being removed from through the Eucumbene portal by means of trucks hauled by battery-powered and mains-powered locomotives, the battery-powered locomotives being used where the working face is close to the surface and the others where the working face has progressed deeper. The spoil is deposited outside the portal and removed to the dumping ground by Euclid rear-dump trucks. At the junction shaft the excavated rock is being removed in a similar manner with the exception that a

* See WATER POWER, April, May, June 1953, pp. 131, 164, 204.

† An account of this project was published in the December 1956 issue of WATER POWER.

Fig. 1. Goodman locomotive and muck train working at Eucumbene portal

Fig. 2. Muck car discharging into muck pocket at junction shaft:

hoist, with a speed of 400 ft. per min., carries the rock to the surface.

Compressed air for the operation of the drilling equipment is being supplied at the Eucumbene portal by six Consolidated Pneumatic tandem two-stage compressors rated at 680 cu. ft. per min. at a pressure of 100 lb. per sq. in. At the junction shaft the greater quantity of air required is being supplied by ten Atlas AR4 two-stage compressors giving 760 cu. ft. per min. at 100 lb. per sq. in. The compressed-air supply is carried to the working face by 8 in. diameter air lines.

Ventilation is all important in a tunnel of this length, and it is provided in this instance by Aerex fans giving a supply of 20,000 cu. ft. per min. For 4,500 ft. the air travels along a 36 in. diameter air duct and then at this interval a booster fan is installed to ensure that the pressure is maintained.

Two other pipes are fastened to the roof of the tunnel beside the ventilation and compressed-air pipes. They are a 4 in. water-supply pipe and a 14 in. water-exhaust pipe.

Key staff for the contractors Kaiser-Walsh-Perini-Raymond were brought from the United States to Australia and they trained Australian and immigrant workmen. To keep tunnel driving going at the maximum rate of progress three shifts per day were habitually worked every day and six days in every week. In every shift 69 men were employed and they were able to break many rock-tunnel driving records.

At the present time work is going ahead rapidly. In the main tunnel a record advance of 402 ft. was made in six consecutive days, and hardly had this feat been celebrated when a further record advance of 481 ft. was established in a similar period. The contractors awarded silver medals to the men constituting the crews in acknowledgement of this achievement. Goodman Conway shovels and locomotives were used to handle and remove the broken rock. The illustrations showing operations in progress are reproduced by courtesy of Kaiser Engineers of Oakland, California.

"English Electric" Current Transformers for Equipments up to 15 kV. The English Electric Co. Ltd. have issued a new publication (SG/335) describing their ranges of standard current transformers for use on equipments up to 15 kV, with ratios conforming with the rated primary currents of B.S. 81 : 1936 and B.S. 2046 : 1953 for instrument and protective transformers respectively. Six basic types are used. Transformers can also be supplied for special applications, ratios or ratings. The publication also gives a brief theory of current transformers and answers a few of the problems that commonly arise.

Passing of an Old Landmark

TWO famous old waterwheels at the Bakewell Works of the D.P. Battery Co. Ltd. have now been replaced by a modern hydro-electric plant consisting of a "Gilkes" water turbine driving an "English Electric" generator. The two wheels, which were a feature of historic interest in Bakewell, were installed in 1827 and 1852 respectively, to drive a cotton mill which was originally built by the great Arkwright in 1777; this mill was one of the earliest to be driven by water power in the country. Ever since The D.P. Battery Co. Ltd. purchased the then disused building and surrounding property in 1898, the main use of the waterwheels was to generate d.c. current for the manufacture of storage batteries.

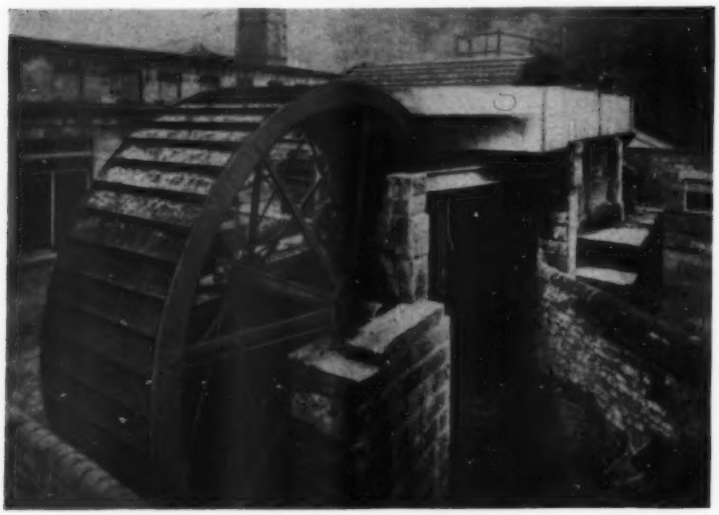


Fig. 1. The old waterwheels at the D.P. Battery works

The new turbine, manufactured by Gilbert Gilkes & Gordon Ltd., Kendal, is of the horizontal Francis type developing 150 h.p. at 213 r.p.m. under a head of water of 21·5 ft. The volume of water at this rating is 74·5 cusecs. Water to the new turbine flows through two sluice doors with worm-operated rack and pinion lifting mechanism giving a clear waterway 5 ft. wide × 6 ft. deep.

The turbine drives an "English Electric" 100 kW, 100 volt d.c. 750 revs. per min. generator of the protected type through a David Brown speed-increasing gear unit. Output from the generator is controlled by an English Electric cubicle-type panel, and supplements the power produced by a steam turbo-generator set and a diesel-driven set. The new generator runs steadily in parallel with both of these sets without the necessity of any automatic voltage regulating equipment, although three different types of governor gear are used in the three different types of prime mover. The control panel incorporates an air-break circuit-breaker fitted with arcing chambers that obviate blow-out coils and afford maximum breaking capacity.

The maximum power output of the old equipment was 66 kW, so that the new set has an output 50% greater using the same head of water.

The larger of the old waterwheels—the one which broke down—was built in 1827 by the firm of Hewes and Wren of Manchester, and was 25 ft. in diameter and 18 ft. wide. This wheel had 70 buckets and each held about half a ton of water. Under normal working conditions the total weight of water in the descending side of the wheel was about 10¼ tons. To deal with such a heavy weight the wheel would have had to be of very massive structure if the power had been transmitted through the spokes and axle as with the undershot type of wheel. To avoid these excessive stresses a series of teeth was arranged round the inner circumference to engage with a pinion at a point just below that at which water entered the buckets. Thus the weight of the water was applied more or less directly

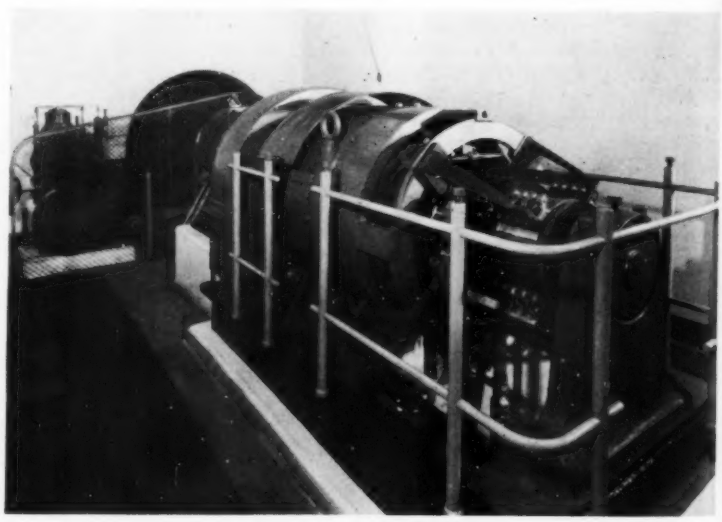


Fig. 2. The Gilkes/English-Electric 100 kW d.c. set

to the very strong pinion wheel, nearly 5 ft. in diameter and 14½ in. wide, which operated the shafting in the mill.

Breakdown of the larger wheel was caused by the fracture of one of the heavy teeth around the wheel, which became jammed against the pinion. Many more teeth were stripped and several of the heavy cast-iron segments were broken. All the teeth in the massive pinion wheel were torn away, the waterwheel frame supporting the buckets was cracked, and a large 10 ft. diameter driving wheel in the works was displaced and cracked. As the wheels had considerable interest historically, the damage was reported to the Town and Country Planning Authority who agreed with The D.P. Battery Company that nothing could be done to save the old wheels, which have now been removed and replaced by the new generating set which we have described.

New Allis-Chalmers Tracto-Loader

The new Allis-Chalmers Tracto-Loader Model TL-12D combines handiness and speed. A 70 h.p. 6-cylinder diesel engine, driving all four wheels through a hydraulic torque converter, gives a travelling speed of up to 25 m.p.h. on the road and provides ample power for lifting the loaded 1⅛ cu. yard bucket from the ground to 10 ft., its maximum height, in 7 sec. The hydraulic torque-converter drive is claimed to give smooth continuous crowding and to eliminate wheel spin, while the clutch-type transmission enables the operator to change direction instantly by the use of a single control lever. Power-assisted steering speeds up turning and manoeuvring in all operating conditions, contributing to a faster time cycle, greater output, and less fatigue on the part of the operator.

The rear-wheel steering turns the machine inside a 19 ft. 10 in. radius.

Metalclad Outdoor Switching Unit

South Wales Switchgear Limited have developed a 33 kV metalclad switchgear unit, of the air-insulated type, for outdoor service, for which two outstanding advantages are claimed. In the first place it is extremely economical in space compared with the open-type layout, and can thus be erected in hilly country with a minimum of levelling; and secondly, it is protected from weather effects by a simple metal housing —a factor of some importance in exposed situations. The unit centres are spaced at 6 ft., and the depth

from back to front is 12 ft. A six-panel switchboard can thus be accommodated in an area measuring only 36 ft. by 12 ft., plus, of course, a space for removing the breaker in front of the unit. Interior heaters can be provided if necessary.

The units are classified as porcelain/air insulated, with vertical isolation and horizontal withdrawal, fully interlocked and fitted with automatic "positive drive" shutter gear. The busbar and feeder chambers are completely separated by a steel barrier and are freely ventilated through louvres. A further feature of note is that the oil circuit breaker can be inspected *in situ* in all weathers.

The first installation of this kind was recently put into commission by the South Wales Electricity Board and consists of a 33 kV 1,000 MVA seven-panel switchboard, and a similar installation is to be erected at the grid station under construction at Cardiff.

Abstracts from the World Technical Press

Mauvoisin Development

Generation at Fionnay, the upper stage of this great Swiss hydro-electric development, started last August, and work on the installations of the lower stage, at Riddes, has advanced at such a rate that the whole scheme is expected to be in operation by the end of this year. This has given the undermentioned newspaper the opportunity to publish a special issue exclusively devoted to this major Swiss project which is to increase the aggregate production of electric energy in the country by no less than 6%. The most conspicuous item of civil engineering work is undoubtedly the Mauvoisin dam itself, an arched structure 237 m. in height by 520 m. in length at the crest, built at elevation 1,960 m. at a remote spot very difficult of access and, in winter, frequently cut off by avalanches. The dam, which involved the placing of almost 2 million cu. m. of concrete, creates a useful storage of 180 million cu. m. The aggregate length of the network of tunnels exceeds 33 km., including 10 km. long sections driven without intermediate adits through rock which, at places, was anything but sound. The equipment of the Fionnay underground powerhouse consists of three vertical generating sets with an output of 82,500 to 127,500 kW; the Francis turbines, designed each to pass 11·5 cu. m. per second, operate from a head varying between 309 and 474 m., the latter figure being a record for this type of turbine. The runners, which develop each 62,800 h.p. at 750 r.p.m., are remarkable for their small size, being no more than 1·55 m. in diameter, with vanes not exceeding 17 cm. in width at the inlet and about 30 cm. at the outlet. The water discharged by the Fionnay plant flows into a 180,000 cu. m. balancing reservoir from which a power tunnel 14,720 m. in length, connecting with a double line of penstocks, conveys it to the Riddes power station, operating from a maximum gross head of 1,015·7 m. The five generating sets at Riddes each consist of a 67,000 kVA horizontal alternator coupled on either side to a Pelton wheel developing 34,200 h.p. at 500 r.p.m., and absorbing 2·875 lit. per second. Once completed, the yearly production of the Mauvoisin Development will reach 761 million kWh, of which no less than 79% will be valuable winter energy. The problems of energy transport, interconnection and exchanges are reviewed and discussed; the general map of the 225 kV Swiss system shows that the Riddes plant can operate in interconnection with the French (Génissiat), Italian and German grids. French interest in the scheme is illustrated by the fact that EDF have subscribed 10% of the capital of Forces Motrices de Mauvoisin, S.A. Among other articles of particular interest in the issue under review, we should like to mention: "Work organisation at Mauvoisin," "Essay on teamwork," "Supplying the Mauvoisin construction sites with electric energy," "Organisation of transport and cement supply," "Avalanche protection and rescue columns." Attention is also drawn to "Some aspects of Swiss hydro-electric economy," which deals with specific Swiss conditions. (Various authors, *La Nouvelle Revue de Lausanne*, No. 254, Oct. 28, 1956, 72 pp., 77 ff.)

Frost Cracks in Concrete

The resistance capacity of concrete to frost is a problem of the utmost importance, especially in the case of dams and structures erected at high altitudes. Since 1953, tests have been carried out at the EDF Laboratory at Albertville for the purpose of ascertaining to what extent, and how, the effects of frost can be checked. The article describes these tests and analyses their results, the first instalment examining in detail the influence of the various factors involved—cement, aggregates, and granulometry. The second instalment begins with a report on the tests effected with various additional products. Then follows a methodical study of the various combinations of cement, aggregates and air-entrainers, supported by numerous graphs showing the test results. The paper ends with a paragraph on the influence of exposure to cold, in which the effects of artificial and natural frost are compared. (J. Orth, Head of Works Department, EDF, Alpine Region II, *Construction*, Vol. XI, No. 6, June 1956, 10 pp., 15 ff.; No. 7, July 1956, 9 pp., 10 ff.)

Hydro-Steam Power Plant

The presence of economically workable coal deposits beside a possible hydro-electric site on Eden Ridge, Coos County, Oregon, has induced Pacific Power & Light Co. to start investigations which may result in the simultaneous development of electric power in a 100,000 kW thermal generating plant as a companion to a 67,500 kW hydro scheme. P.P. & L. has filed applications with the Oregon Hydro-electric Commission and the Federal Power Commission for preliminary permits to investigate the proposed Eden Ridge site on the South Fork of the Coquille River. The company also holds prospecting rights in the adjacent coal fields which, according to preliminary exploration, may hold a reserve of approximately 50 million tons. The proposed hydro plant would make use of a 12 mile loop in which the river drops 1,650 ft. in its swing around the ridge; a 2 mile tunnel would convey water from the reservoir created by a 170 ft.

high dam erected at a point behind the ridge and about 23 miles upstream from Powers. Studies of the project may, however, show that a dam as high as 250 ft. and a generating plant possibly as large as 100,000 kW will be feasible. (*Electrical World*, September 3, 1956, pp. 78/79, 2 ff.)

New Underground Powerhouse in U.S.

The 128,000 kW underground power plant at Haas, on the north fork of the Kings River, Fresno County, California, will be 56 ft. wide, 105 ft. high and 125 ft. long. The underground type was adopted in this instance by Pacific Gas & Electric Co. on grounds of economy, being lower in capital cost and producing more power as a result of decreased head loss. The site involves an ideal massive granite formation, and the profile at the lower end of the high-head (2,400 ft.) penstock is relatively flat. Several improved features will further contribute to economy. For example, there is no separate excavation for the valve-chamber: the shut-off valves are located in the cavern of the machinery hall; moreover, the paving of the 2,000-ft. long tailrace tunnel will provide an access roadway during construction and, finally, the arch of the powerhouse will be supported by rock bolts rather than by a thick concrete lining. (*Engineering News-Record*. Vol. 157, No. 16, October 18, 1956, pp. 26/27, 2 ff.)

Maraetai Project, N.Z.

The author gives data on the general layout of this 180,000 kW scheme and a description of the works—diversion tunnel and spillway, main penstock intakes and screens, intake gates and lifting equipment. He then examines and discusses the design and construction of the five penstocks between the dam and the powerhouse. The main and final section of the paper deals with the arch dam itself and deals with the following matters:— Physical properties of abutment rock, grouting of abutment and country rock, analysis of dam by both the elastic-arch theory and the trail-load method, comparison of stresses and direction of arch thrusts, comparison of observed deflection and trial load deflections, and discussion of results. A detailed analysis of the costs, which result in approximately £52 per kW, is appended. (L. S. James, *New Zealand Engineering*, Vol. 11, No. 9, Sept. 15, 1956, p. 282, 14 pp., 12 ff.)

Tingambato Project

This 150 MW plant, the fifth of six generating stations of Mexico's Miguel Aleman system, is nearing completion. The system drains 1,300 sq. miles of mountainous regions in southern central Mexico, and comprises dams and waterways controlling water which, beginning at 8,600 ft. above sea level, flows through the penstocks of five plants, Tingambato being the lowermost at an elevation of 2,264 ft. The project includes two tunnels driven nine miles through mountains, a 1,127 ft. vertical-shaft penstock, and an underground powerhouse, all excavated in granite. The Santo Tomas dam is of the rockfill impermeable centre type, 171 ft. high, 20 ft. wide at its crest, and 502 ft. long, creating a reservoir with a working capacity of 22·6 million gallons. A tunnel 6·3 miles long discharges into the regulating basin created by the Pinzanes dam, 200 ft. high, 16·5 wide at its crest and 846 ft. long. After passing through a second tunnel 2·7 miles in length, a 90° elbow leads the water through the longest vertical penstock in Mexico to the three 70,000 h.p. Francis turbines, each running at 600 r.p.m. and driving a 50,000 kVA generator. The underground powerhouse is 207 ft. long, 114 ft. high, and 39 ft. wide. (*Electrical World*, Sept. 24, 1956, pp. 48/49, 4 ff.)

Guarico Dam

Though purely conceived as an irrigation structure, this earthfill dam, erected on the Guarico river 190 miles south of Caracas, deserves special mention not only for its size but also for the uncommonly short time in which it was completed. The dam is nine miles long, 100 ft. high, 655 ft. wide at the base and creates a reservoir of 1·5 million acre ft. It was not until late in 1955 that the major contracts were let, involving placement of 15 million cu. yards of gravel and clay in the embankment and 130,000 cu. yd. of concrete in the 435 ft. spillway. Since the Venezuelan Government wanted to gain a year's time in getting the project in operation, they specified substantial completion by August 1956, which allowed the contractors only six months of high-gear operation. Another difficulty was that the 650,000 cu. yard of rock to face the upstream side of the dam had to be hauled from a distance of 41 miles. At one time, early this year, there were 900 pieces of equipment on the job and the dam was completed in time to capture this year's flood flow on the Guarico river that began in August. (*Engineering News-Record*, Vol. 157, No. 13, Sept. 29, 1956, p. 51/52, 3 ff.)

Welded Penstocks

This symposium in three parts originated in the Melbourne Division of the Institution of Engineers, Australia, and was presented before a joint meeting of the Division and its Civil Engineering Branch on the 15th June, 1954.

I.—*Metallurgical Aspects of Welded Steel Penstocks.* The first section outlines the physical properties required of steel plates and welded joints in welded steel penstocks, and discusses ways in which these may be met, particularly if commercial quality steel plate has to be used. The second section describes the main features of brittle fracture in steel and suggests how this hazard can be minimised in penstocks. The last section outlines the testing that should be carried out during construction, referring particularly to radiographic examination and hydrostatic testing. (I. J. Ferris.)

II.—*Tunnel Lining and Penstock Construction.* This paper gives a brief description of the layout and construction of the steel tunnel lining and penstocks of the Eildon dam. It describes particularly the testing and heat treatment of the steel plates and the results obtained, the testing and choice of welding electrodes, and the final warm- and cold-water pressure tests on the completed installation. (Milton G. Speedie.)

III.—*Welding and Inspection of Tunnel Lining and Penstocks for the Eildon project.* The final part of the symposium deals briefly with the assembly and welding procedures used for the fabrication of the steel tunnel lining and penstocks, and outlines the visual and radiographic inspection adopted. In his conclusion, the author claims that in instances such as at Eildon, when extensive X-raying is not possible,

constant visual inspection of hand welding is more reliable than gamma-radiography, which should only be used as a secondary check; the low level of contrast obtained with gamma-rays makes the detection of small defects very difficult, particularly where, for practical reasons, it is not possible to grind the weld surfaces smooth. For automatic welding, where the weld surfaces are smooth and where small defects are normally accompanied by pipes, gas-holes, etc., which are easily detected on a radiographic film, the reliance on gamma-radiography is more justified and, in view of the difficulties of visual inspection, must be used as the primary method of inspection. (J. E. Bonwick.) (*The Journal of the Institution of Engineers, Australia*, Vol. 28, No. 6, June 1956, p. 133, 17 pp., 21 ff., 8 tables.)

Columbia River Power

The dispute between the United States and Canada over the Columbia River power development is coming to a head with the two sides still far apart, and this on a question that is exceedingly complex, devoid of ready solution, and which involves vast amounts of electrical energy. The issue has been two years in forming, since Canadian spokesmen began talking about possible diversions of Kootenai River waters into the Columbia, and Columbia River waters into the Fraser River basin. This was and is still considered in U.S. as a "diversionary tactic" to secure Canada a better bargaining position over compensation for water stored in the Canadian portion of the Columbia River that would serve U.S. powerhouses downstream. However, early in August 1956, General McNaughton, chairman of the Canadian section of the International Joint Commission, stated that engineering studies showing the feasibility of the Columbia-Fraser diversion had been completed, and that the figures will soon be made public, denying at the same time that Canada had dropped its diversion plans. High-level diplomatic discussions between the two countries were suggested by Canadian Prime Minister St. Laurent to President Eisenhower last April at White Sulphur Springs. This article gives a comprehensive survey of the whole issue and includes a map showing all the major dams, existing or planned, that are involved in the Canadian diversion plan. (Howard Jacoby, Associate Editor, *Engineering News-Record*, August 23, 1956, p. 21, 5 pp., 7 ff.)

Soviet Power Plans

An account is given of a three-hour interview granted to Mr. Shelton Fisher, of the McGraw-Hill concern, by Georgi Malenkov, director of the Ministry of Power, U.S.S.R. Malenkov spoke assuredly of an intercontinental 400 kV grid linking water resources in Siberia with the Moscow power centre by 1960. The grid is to be fed from steam, water and nuclear power plants; the most impressive of the hydro stations will be Bratsk in Siberia with 200,000 kW generating units and a total capacity of 3·6 million kW. He added that the two-hour time difference between east and west made it possible to use the plants to an optimum degree as the power could be shifted as the sun moved and the demand changed. Bratsk dam, located on the Angara river, is to be three miles across and 425 ft. high; it is scheduled to start generation in 1960 and a yearly production of 20,000 million kWh is expected. Total hydro power consumed in Russia in 1955 was 28,000 million kWh. Malenkov told his visitor, the first American allowed to make an extensive tour of Soviet power facilities in recent years, that the existing hydro installations represent only 2% of the potential development and that ultimately hydro sources will generate 1,700,000 million kWh annually, that is to say 500,00 million kWh more than the total electrical energy consumed by the entire world from all sources in 1953. (*Engineering News-Record*, Vol. 157, No. 15, Oct. 11, 1956, pp. 27/28, 2 ff.)

Brownlee Development

The rockfill Brownlee dam, on the upper reaches of Hells Canyon, Snake river, constructed by Morrison-Knudsen for the Idaho Power Company, represents the first phase of this development, on which work started in November 1955. A cofferdam to divert the Snake river through a half-mile-long tunnel around the dam site was closed recently and now the all-out race has begun against a schedule which calls for completion of the 395-ft. high dam, its powerhouse and a host of appurtenant works, by December 1958. Brownlee will initially have a capacity of 360,000 kW, with an ultimate installed capacity of 540,000 kW. It is the first and largest of three companion schemes planned by Idaho Power Company for the Hells Canyon area that will glean an eventual total capacity of 1,175,000 kW from the Snake river. The second dam, Oxbow, will be located 12½ miles downstream from Brownlee, and the third will be Hells Canyon dam, 23 miles below Oxbow. (*EM-Kayan*, Vol. 15, No. 8, October 1956, p. 10, 3 pp., 10 ff.)

A Brazilian Project

After five years of planning, work has finally begun on the Tres Marias dam, which will be built on the Sao Francisco River, north of the mining town of Belo Horizonte. This scheme resembles, on a smaller scale, the St. Lawrence Seaway project in that its main purpose will be to provide for the navigation of sea-going ships for 800 miles up the San Francisco. Only a small portion of the 8,600 ft. long dam will be used for the power plant and the incidental intake works, spillway and flood control, and more than 5,000 ft. will consist of an earth structure built from the left bank of the river. Generating capacity, about 180,000 kW at the outset, will be increased eventually to 500,000 kW. The reservoir created by the 230 ft. high dam will extend 93 miles upstream. Completion of the whole project is expected to take 8 to 10 years. (*Engineering News-Record*, Vol. 25, No. 18, November 1, 1956, p. 53.)

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